Boiling Water Reactor
GE BWR/4 Technology
Technology Manual

Chapter 7.3

Reactor Protection System

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7.3 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the system's purposes.
2. Explain the logic used by the system to generate a trip signal.
3. Explain how a trip signal causes control rod insertion, and what ensures a scram is completed once it is initiated.
4. Explain the fail-safe features of the system.
5. Given a scram signal, state the reason for each scram signal, the conditions which may bypass it, and the reason each bypass is allowed.
6. Explain the purpose of the reactor mode switch.
7. Explain how this system interfaces with the following systems:
   a. Control Rod Drive System
   b. Neutron Monitoring System
   c. Instrument Air System

7.3.1 Introduction

The purposes of the Reactor Protection System (RPS) are to initiate a reactor scram to preserve the integrity of the fuel cladding, to preserve the integrity of the reactor coolant system, and to minimize the energy which must be absorbed following a loss of coolant accident.

The functional classification of the RPS is that of a safety related system. Its regulatory classification is a reactor trip system.

The Reactor Protection System (RPS) includes the motor generator power supplies with associated control and indicating equipment, sensors, relays, bypass circuitry and switches that cause rapid insertion of control rods (scram) to shut down the reactor.

The reactor protection system is a fail safe system, composed of two independent trip systems, A and B, each made up of two channels (Figure 7.3-1). Trip system A consists of channel scram logics A1 and A2 while trip system B consists of channel scram logics B1 and B2. Each channel scram logic receives inputs from at least one independent sensor monitoring each of the critical parameters shown in Figure 7.3-2. An unbypassed trip occurring in any trip logic(s) of trip system A, together with an unbypassed trip occurring in any logic(s) of trip system B, generates a reactor scram. Note that a trip of one trip system, with the other trip system not tripped, does not cause a reactor scram.

The automatic trip logic of the RPS is arranged for the most part in a one- out-of-two-twice logic. The logic remains energized in the non-scram condition. Deenergizing the two trip systems initiates a reactor scram by venting air from the control rod drive scram valves causing the control rods to be inserted into the core.

7.3.2 Component Description

The major components of the reactor protection system are discussed in the paragraphs that follow.

7.3.2.1 Power Supplies

The two RPS buses receive power from independent divisional power supplies through high inertia RPS motor generator (MG) sets. The high inertia is provided to each of the MG sets by a flywheel. The flywheel will maintain voltage and frequency within 5% of rated values for a minimum of 2 seconds following a total loss of power to the drive motor. This ensures against the effects of momentary changes to the electrical supply of the MG set.

The two RPS buses have alternate power supplies available from nonessential power transformers that are provided for maintenance periods on one of the motor generator sets. To ensure against supplying both RPS buses from an alternate source, an interlock is provided (Figure 7.3-3) that will not allow both alternate supply breakers to be closed at the same time. This interlock also prevents paralleling an MG set with its alternate power supply.

In addition to the RPS, the RPS buses supply power to the Primary Containment Isolation System (PCIS), the Process Radiation Monitoring System, and the Neutron Monitoring System.

The RPS is arranged in a one-out-of-two-twice logic scheme. Each trip system is completely independent of the other. The RPS logic, Figure 7.3-1 and 7.3-4, consists of two separately powered trip systems. Each trip system contains two trip channel logics. The trip logics of system A are designated channels A1 and A2 and both receive at least one input signal from the same monitored parameter; both trip channels are identical. Thus, any monitored parameter supplying an automatic trip signal would have a minimum of four sensors.

An out of tolerance sensor in either trip channel's logic, A1 or A2, would cause a trip in system A. A trip condition in system A would deenergize the A scram valve solenoid coil for each control rod. This condition is referred to as a half scram. Likewise, any sensor in trip system B out of tolerance (trip condition), will cause a half scram.

To produce a reactor scram, both trip systems A and B must be in the trip condition. The overall logic is termed one-out-of-two twice.

In addition, two methods are provided for manually causing a reactor scram. Four pushbuttons are provided in the control room (one pushbutton per channel), each of which will deenergize its respective channel when pushed, causing a manually actuated reactor scram. Placing the reactor mode switch into the "SHUTDOWN" position will also cause a manually actuated reactor scram by deenergizing all RPS channels.

7.3.2.2 Scram Valve Logic

The hydraulic control units (HCUs) for the 137 control rods are physically located in two groups on opposite sides inside primary containment. To provide electrical separation and to minimize current requirements through contacts and relays, the scram solenoids and their respective control rods are arranged into four scram groups. This grouping maintains the same logic(s) as shown in the RPS chapter figures; therefore, the four groups have been omitted for clarity.

7.3.2.3 Scram Valve Arrangement

Each of the 137 control rods is equipped with two scram solenoid valves as shown in figure 7.3-5. These valves are normally in an energized, untripped condition and control the air supply to the control rod drive scram inlet and outlet valves.

The scram inlet and outlet valves open with spring pressure and close (normal position) with air pressure. The scram inlet valve controls the scram water provided to the control rod drive by the scram accumulator. The scram outlet valve aligns the top of the control rod drive piston to the scram discharge volume. A reactor scram is initiated when both scram solenoid valves are deenergized, venting the air from the scram valves. When spring pressure overcomes the air pressure, the scram inlet and outlet valves open. Opening of the scram inlet valve allows the stored energy of the scram accumulator to be felt on the bottom of the drive piston. Opening of the scram outlet valve aligns the top of the drive piston with the scram discharge volume. With 1500 psig of water pressure below the drive piston and atmospheric pressure above the drive piston, a large differential pressure is created to force the control rod rapidly into the core.

In addition to the scram pilot solenoid valves, there are two DC backup scram solenoid valves which provide a second means of controlling the air supply to the scram valves for all control rods. The DC solenoid for each backup scram valve is normally deenergized. The backup scram valves are energized (to independently vent the air headers) when both trip system A and trip system B are tripped.

Figure 7.3-5 shows that when the solenoid for each backup scram valve is energized, the backup scram valves vent the air supply for all scram valves. This action initiates insertion of every control rod, regardless of the action of the individual scram pilot valves.

Note that on loss of air pressure or electrical power a reactor scram would be initiated. This is a fail safe feature of the reactor protection system.

7.3.3 System Features and Interfaces

A short discussion of system features and interrelations between this system and other plant systems is given in the paragraphs that follow.

7.3.3.1 RPS Operating Modes

The four principal modes of the reactor protection system are: "SHUTDOWN", "REFUEL", "STARTUP/HOT STANDBY", and "RUN". The selection of the various modes is accomplished via a key lock selector switch appropriately called the reactor mode switch. The reactor mode switch interlocks the various control functions depending on the plant operating condition. The reactor mode switch is manually placed in one of the four positions which places into effect the corresponding trip functions.

Placing the reactor mode switch in "SHUTDOWN" initiates a reactor scram; disables the main steam isolation valve (MSIV) closure scram and enables the bypass of the scram discharge volume high level scram.

Placing the reactor mode switch in "REFUEL" disables the MSIV closure scram. The refuel position also enables the bypassing of the scram discharge volume high level scram and allows single rod withdraw.

Placing the reactor mode switch in "STARTUP /HOT STANDBY" allows the operator to withdraw control rods for a plant startup and disables the ability to bypass the scram discharge volume high level scram. The MSIV closure scram is still bypassed.

Placing the reactor mode switch in "RUN" selects the APRM thermal power scram and fixed scram trip level while removing the 15% power APRM scram. The intermediate range monitoring system scram signals are disabled except for the IRM Hi Hi and associated APRM downscale scram. The MSIV closure scram is unbypassed.

7.3.3.2 Scram Functions and Bases

Each of the scram functions and the bases associated with these functions are discussed in the paragraphs that follow, listed in Table 7.3-1, and illustrated in Figure 7.3-2.

Manual Scram Pushbuttons

Four manual scram pushbuttons are provided to allow the control room operator to scram the reactor in anticipation of automatic scrams and to follow up automatic scrams.

Individual Rod Scram Switches

Each hydraulic control unit (HCU) has an electrical box associated with it. This box is physically located at the HCU and contains two switches. Each switch assigned a scram pilot solenoid valve, one for each RPS channel. These switches are used for scram solenoid valve testing and control rod scram testing.

Mode Switch in Shutdown

The mode switch provides appropriate protective functions for the condition in which the reactor is to be operated. The reactor is to be shut down with all control rods inserted when the mode switch is in "SHUTDOWN". To enforce the condition defined for the "SHUTDOWN" position, placing the mode switch in the "SHUTDOWN" position initiates a reactor scram. This scram is not required to protect the fuel or nuclear system process barrier, and it bears no relationship to minimizing the release of radioactive material from any barrier. The scram signal is removed after a 10 second time delay, permitting a scram reset which restores the normal valve lineup in the control rod drive hydraulic system. This time delay is independent of the RPS time delay reset also set at 10 seconds.

Scram Discharge Volume High Level

The scram discharge volume receives the water displaced by the motion of the control rod drive pistons during a scram. Should the scram discharge volume fill up with water to the point where insufficient volume remains for the water displaced during the scram, control rod movement would be hindered in the event a scram were required. To prevent this situation, the reactor is scrammed when the water level in the scram discharge instrument volume attains a value high enough (60 inches) to verify that the discharge volume is filling up, yet low enough to ensure that the remaining capacity in the discharge volume can accommodate a scram.

High Reactor Pressure

High pressure within the nuclear system process barrier poses a direct threat of reactor coolant boundary failure, and a core power excursion from the void collapse. A nuclear system pressure increase during reactor operation collapses steam voids and results in a positive reactivity insertion. This increases generation of core heat that could lead to fuel failure and to system overpressurization. A scram counteracts a pressure increase by rapidly reducing generation of the core fission heat. The nuclear system high pressure scram setting of 1043 psig was chosen slightly above the reactor vessel maximum normal operating pressure to permit normal operation without spurious scrams, yet provide adequate margin to the maximum allowable nuclear system pressure. The high pressure scram works in conjunction with the safety/relief valves to prevent nuclear system pressure from exceeding the maximum allowable pressure. The high pressure scram setting also protects the core from exceeding thermal hydraulic limits that may result from pressure increases during events that occur when the reactor is operating below rated power and flow.

Main Steam Line Isolation Valve Closure

Closure of the main steam line isolation valves, with the reactor at power, can result in a significant addition of positive reactivity to the core as the nuclear system pressure rise collapses steam voids. The main steam line isolation valve closure scram is required to provide a satisfactory margin below core thermal hydraulic limits for this category of abnormal operational transients.

Each MSIV contains two stem mounted limit switches which input into the RPS trip logic (one for each RPS trip channel).

The <10% closure setting for these valves was selected to give the earliest positive indication of valve closure to limit the resultant pressure rise. The Reactor Protection System logic for MSIV closure trip is arranged to look only at the number of steam lines isolated vs the number of valves closed. The MSIV closure logic is shown in Figures 7.3-6. The logic is arranged so that with one line isolated no trips are generated, with two lines isolated a half trip will be generated sometimes, and isolation of three lines will produce a full reactor scram.

Turbine Stop Valve Closure

Turbine stop valve closure inputs to the RPS are generated from valve stem position switches mounted on the main turbine stop valves. Each switch actuates when the stop valve is <10% closed. Closure of the turbine stop valves, with the reactor at power, can result in a significant addition of positive reactivity to the core as the nuclear system pressure rise collapses steam voids. The turbine stop valve closure scram, which initiates a scram earlier than either the neutron monitoring system or nuclear system high pressure, is required to provide a satisfactory margin below core thermal hydraulic limits for this category of abnormal operation transients. Although the nuclear system high pressure scram in conjunction with the pressure relief system, is adequate to preclude overpressurizing the nuclear system, the turbine stop valve closure scram provides additional margin to the nuclear system pressure limit.

The turbine stop valve closure scram is automatically disabled when turbine first stage pressure is below 30% of rated conditions.

Turbine Control Valve Fast Closure

Turbine control valve fast closure sends inputs to the Reactor Protection System from pressure switches on each of the four fast acting control valve hydraulic mechanisms. These hydraulic mechanisms are part of the turbine control valve and they are used to effect fast closure of the turbine control valves in the event this action is required.

This rapid closure results in a situation similar to a turbine stop valve closure. Therefore, this scram is provided for the same reasons as those discussed for turbine stop valve closure scram. The turbine control valve fast closure scram is automatically disabled when turbine first stage pressure is below 30% of rated conditions.

Main Steam Line High Radiation

High radiation in the vicinity of the main steam lines could indicate a gross fuel failure in the core. When high radiation is detected near the steam lines, a scram is initiated to limit the fission products released from the fuel. This same high radiation condition also signals the Primary Containment Isolation System to isolate the Main Steam System to limit the release of fission products. The setting for the high radiation trip is selected high enough above background radiation levels to avoid spurious scrams, yet low enough to promptly detect a gross release of fission products from the fuel.

Reactor Vessel Water Level Low

A low water level in the reactor vessel indicates that the reactor is in danger of being inadequately cooled. The effect of a decreasing water level while the reactor is operating at power is to decrease the reactor coolant inlet subcooling. The effect is the same as raising feedwater temperature. Should water level decrease too far, fuel damage could result as steam forms around fuel rods. A reactor scram protects the fuel by reducing the generation of fission heat within the core.

The reactor vessel low water level scram setting of 12.5 inches was selected to prevent fuel damage following those abnormal operational transients caused by single equipment malfunctions or single operator errors that result in a decreasing water level in the reactor vessel. Specifically, the scram setting is chosen far enough below normal operating levels to avoid spurious scrams but high enough above the top of the active fuel to assure that enough water is available to account for evaporation losses and displacements of coolant following the most severe abnormal operational transient involving a level decrease. The selected scram setting was used in the development of thermal hydraulic limits, which set operational limits on the thermal power level for various coolant flow rates.

Drywell Pressure Scram

High drywell pressure may indicate a break in the reactor coolant pressure boundary. It is, therefore, prudent to scram the reactor in such a situation to minimize the possibility of fuel damage and to reduce the energy transfer from the core to the coolant, which in turn minimizes the energy that the suppression pool may be required to absorb. The high drywell pressure scram setting of 1.69 psig was selected to be as low as possible without inducing spurious scrams.

Neutron Monitoring System Trips

To provide fuel cladding protection against excessive power generation, neutron flux is monitored and used to initiate a reactor scram.

IRM Scrams

An IRM scram signal is generated if reactor power exceeds a preselected setpoint or if an IRM becomes inoperable. An IRM inoperable trip is caused by any one of the following conditions: high voltage power supply low voltage, channel function switch not in the operate position, or one of the drawer modules unplugged. The IRM high high scram signal will be sent to the RPS logic any time one of the IRMs is greater than 120/125 of scale on any range of the IRMs. All IRM scram signals are disabled when the reactor mode switch is in the "RUN" position except for the IRM Hi HI and associated APRM downscale scram.

APRM Scrams

Scram signals are generated by the APRM logic circuits under four different conditions: inoperable APRM circuit, high neutron flux with the reactor mode switch position in other than the "RUN" position, high neutron flux with the reactor mode switch in the "RUN" position, and high thermal power (high heat flux) for the existing recirculation loop driving flow. If one of the above listed conditions exists, a trip signal from the APRM channel (or channels) detecting this condition is generated.

The APRM inoperable trip is caused by the APRM function switch being out of the operate position, insufficient LPRM inputs feeding the APRM logic, the associated flow converter being INOP, or if a card in the APRM circuitry is unplugged.

The high neutron flux in other than the "RUN" mode and the high neutron flux in the "RUN" mode scrams are both derived from variable resistor control signals. If the reactor mode switch is in other than the "RUN" position, the fixed neutron flux scram setpoint is set at 15%, and when the reactor mode switch is placed in the "RUN" position, the 118% flux level scram setpoint is inserted in its place.

Finally, the APRM thermal power scram setpoint level is based on the percent of rated recirculation loop flow. There are four flow transmitters on each recirculation loop. Two flow signals are sent to each APRM flow converter, one flow signal from each loop. These signals are then summed to produce a total recirculation drive flow signal to be used for the thermal trip circuitry. This signal is then applied to a slope and bias network which determines the thermal trip reference to be sent to the APRM thermal trip unit. The trip reference is compared to a reactor power signal. If the reactor power exceeds the reference set point for a preset time delay (6-7 seconds) a thermal trip scram signal is generated.

Special Neutron Monitoring System Scrams

During some reactor plant conditions such as performance of core alterations (e.g., fuel loading), it is desirable to scram the reactor if any one signal from any of the neutron monitoring system (NMS) instrumentation indicates an abnormally high power level (high neutron flux), or inoperable conditions, including signals from the Source Range Monitor (SRM) System. This extra precaution will protect personnel by preventing an inadvertent power excursion when the reactor vessel head has been removed. In order to effect this mode of operation of the NMS logic (non-coincident mode), a set of shorting links which normally disable the SRM scram function, are removed from the RPS logic circuit.

Reset Circuit

Once a scram has occurred and the condition causing the scram has been corrected, a manual reset is required to return the RPS and CRD System to a normal, prescram condition.

Three conditions are necessary to reset a scram signal:

1. The scram signal(s) must all be cleared or bypassed
2. Ten seconds must have elapsed since the scram was initiated
3. The reset switch must be momentarily placed in both reset positions

The 10 second time delay function is provided to allow the slowest control rods to be fully inserted into the reactor core before a scram can be reset. This time delay does not apply on a single channel trip (1/2 scram), since there is no control rod motion.

Principle of Operation

The RPS performs its design function by deenergizing the 137 scram pilot solenoid valves (one for each rod), deenergizing the two scram discharge volume solenoid valves, and energizing the two backup scram solenoid valves as shown in Figure 7.3-5.

The scram is achieved by opening the scram inlet and scram outlet valves on each individual rod. This applies 1500 psi accumulator pressure to the "insert" side of the control rod piston and vents the "withdraw" side of the piston to atmospheric pressure in the scram discharge volume.Under normal conditions, the scram inlet and outlet valves are held shut by control air pressure applied through the energized scram solenoid valve. The scram discharge volume vent and drain valves are held open by air pressure applied through the energized discharge volume solenoid valves. The air header which supplies all scram solenoid valves is pressurized through the deenergized backup scram valves.

A scram signal deenergizes the scram pilot solenoid valve for each rod, deenergizes the discharge volume solenoid valves and energizes the backup scram valves thus venting air pressure from the scram inlet and outlet valves and the scram discharge volume valves. Should the individual control rod scram pilot valve fail to shift (e.g., mechanical binding), the backup scram valves are energized and vented to depressurize the scram solenoid valve supply header. Thus, even if a pilot valve failed to shift, its control rod would still scram. A check valve is provided around the down stream backup scram valve so the upstream valve can assist in the header blowdown, or in case the down stream valve fails.

As an aid to understanding the operation of the complete system, a scram signal will be traced through the system. Assume some problem with the Electro Hydraulic Control System causes an increase in reactor vessel pressure, and assume no corrective operator action. As pressure increases, an annunciator will inform the operator that there is a problem. As pressure increases further to 1043 psig, pressure switches will actuate and open contacts N678A, B, C, and D. (Figure 7.3-8). Relays K5A, B, C, and D will all be deenergized. Deenergizing the four K5 relays opens contacts in series with the channel scram sensor relays. Opening of K5A deenergizes channel scram sensor relays K14A and E. Opening contacts on K5C deenergizes subchannel scram relays K14C and G. Opening contacts on K5B deenergizes relays K14B and F. Opening contacts on K5D deenergizes relays K14D and H. Thus, each sensor (pressure switch, in this case) opened contacts to deenergize its associated channel scram sensor relays. Once a scram signal deenergizes a K14 relay, a series contact on the relay opens and prevents the relay from being reenergized (Figure 7.3-4) until the scram signal is clear and the scram reset.

Deenergizing relays K14A and E (A channel) or K14C and G (C channel) will deenergize the A trip system solenoid of the scram pilot solenoid valve (Figure 7.3-4). In like manner, deenergizing K14B and F (B channel) or K14D and H (D channel) will deenergize the B trip system solenoid. When both scram solenoid valves are deenergized, they change position to block the air supply and vent air off the scram valve air operator diaphragm. Now a flow paths exist for air to exhaust from the scram inlet and outlet valve operators, causing them to open rapidly, placing CRD accumulator pressure on the below piston area of the CRDM, and opening an exhaust path to the scram discharge volume from the over-piston area of the CRDM, driving the control rod rapidly into the reactor core.

When a trip occurs in both channels of RPS (full scram) the backup scram valve solenoids will be energized by contacts of the K14 relays. When the backup scram valve solenoids energize, the backup scram valves will reposition and bleed air off the entire scram pilot valve air header, causing any rods with failed (stuck) scram pilot solenoid valves to drive into the reactor core. At the same time that the backup scram valve solenoids are energized, an auxiliary relay in parallel with each solenoid will be energized. These auxiliary relays (K21A and K21B) are utilized to actuate contacts in the scram reset logic (Figure 7.3-7) and to open contacts deenergizing the scram discharge volume pilot valves causing the SDV vent and drain valves to close, isolating the Scram Discharge Volume. Water discharged from the overpiston areas of the CRDMs during a scram will fill the Scram Discharge Instrument Volume and cause an additional reactor scram signal from high level in the Scram Discharge Instrument Volume.

Reset of the reactor scram will not be permitted for a period of 10 seconds (K22 relays) immediately following any scram signal to allow time for the slowest control rod to be fully inserted into the reactor core (Figure 7.3-7). In order to reset the scram, the Reactor Mode Switch must be in "SHUTDOWN" or "REFUEL" and the SDV high level scram signal must be bypassed. Bypassing this trip signal will allow resetting the reactor scram and thus permit draining of the Scram Discharge Volume (SDV vent and drain valves reopen when the scram is reset). Each reset switch must then be rotated to the "RESET" position and released. This energizes the K19 relays which will reenergize the channel scram sensor relays, providing all scram signals are clear or bypassed. This closes channel sensor relay contacts K14A through H which seals in the reset. Once the SDV is drained, the bypass switches for the SDIV scram can be returned to "NORMAL". The Reactor Protection System is now back in the normal operating mode.

Testing

The Reactor Protection System can be tested during reactor operation by five separate tests. The first of these is the manual trip actuator test. By depressing one channel's manual scram button for a trip system, the manual relays (K15) are deenergized, opening contacts to the channel scram sensor relays. After resetting the trip system, the second channel is tripped with its manual scram button. The test is continued for the other channels of the other trip system. The total test verifies the ability to deenergize scram pilot valve solenoids by using the manual scram push button switches. Scram indicator lights verify that the scram sensor relays have deenergized.

The second test is the automatic actuator test, which is accomplished by operating (one at a time) the administratively controlled test switches for each automatic logic. The switch deenergizes the relays for that logic, causing the associated contacts to open. The test verifies the ability of each logic to deenergize the relays associated with the parent trip system.

The third test includes calibration of the neutron monitoring system by means of simulated inputs from calibration signal units.

The fourth test is the single rod scram test, which verifies capability of each rod to scram. It is accomplished by operating toggle switches on the CRD HCU. Timing traces can be made for each rod scrammed. Before the test, a physics review must be conducted to ensure that the rod pattern during scram testing does not create a rod of excessive reactivity worth.

The fifth test involves applying a test signal to each Reactor Protection System channel in turn and observing that a logic trip results. This test also verifies the electrical independence of the channel circuitry. The test signals can be applied to the process type sensing instruments (pressure and differential pressure) through calibration taps. This test is performed in accordance with approved written procedures.

Reactor Protection System response times are first verified during preoperational testing and may be verified thereafter by similar tests. The elapse times from sensor trip to deenergizing the scram sensor relay are measured.

Scram Bypasses

A number of scram bypasses are provided to account for the varying protection requirements depending on reactor conditions and to allow for instrument service during reactor operations. Some bypasses are automatic, others are manual. All manual bypass switches are in the control room, under the direct control of the control room operator. If the ability to trip some part of the system has been bypassed, this fact is continuously indicated in the control room.

Automatic bypass of the scram trips from main steam line isolation is provided when the mode switch is not in "RUN".

The bypass for main steam line isolation allows reactor operations at low power with the main steam lines isolated and the main condenser not in operation. These conditions may exist during startups, during certain reactivity tests connected with refueling, and during hot standby conditions.

The scram initiated by placing the mode switch in "SHUTDOWN" is automatically bypassed after a time delay of 10 seconds. The bypass is provided to restore the Control Rod Drive System valve lineup to normal.

An automatic bypass of the turbine control valve fast closure scram and turbine stop valve closure scram is enabled whenever the turbine first stage pressure is less than 30% of its rated value. Closure of these valves from such a low initial power level does not constitute a threat to the integrity of any barrier to the release of radioactive material.

Bypasses for the neutron monitoring system consists of the capability of the operator to bypass one of the four SRM channels, one of the four IRM channels in each trip system, and one of the three APRM channels in each trip system.

A manual switch located in the control room permits the operator to bypass the scram discharge volume high level scram trip if the mode switch is in "SHUTDOWN" or "REFUEL". This bypass allows the operator to reset the Reactor Protection System, so that the system is restored to operation while the operator drains the scram discharge volume. In addition to allowing the scram relays to be reset, actuating the bypass initiates a control rod block.

Resetting the trip actuators opens the scram discharge volume vent and drain valves. An annunciator in the control room indicates the bypass condition. Automatic scram bypasses are listed in Table 7.3-1.

7.3.4 System Interfaces

The RPS interrelates with all systems which provide parameter inputs to the logic trains. These parameters are listed in Table 7.3-1. Interrelations between this system and other plant systems are discussed in the paragraphs that follow.

7.3.4.1 Control Rod Drive System (Section 2.3)

The CRD System provides the motive force for control rod insertion when the scram inlet and outlet valves open and the collection chamber (scram discharge volume) for the water discharged by the HCUs.

7.3.4.2 Reactor Manual Control System (Section 7.1)

When the Scram Instrument Volume high level scram is bypassed, a signal is sent to the Reactor Manual Control System to prevent rod withdrawal until this scram is unbypassed. This prevents the reactor from being restarted until the volume is drained to below the scram setpoint. This interlock is performed using isolated outputs so that no failure of the control system can prevent a scram.

7.3.4.3 Reactor Recirculation System (Section 2.4)

Above 30% reactor power, as sensed by first stage turbine pressure, and when either the turbine control valves fast close or three out of four turbine stop valves are less than 90% open, an automatic trip of the Reactor Recirculation pumps will occur. The same pressure switches and position switches which input to the RPS scram logic for a Reactor scram. They also provide inputs to the EOC-RPT.

7.3.4.4 Instrument Air System (Section 11.8)

The Instrument Air System supplies the air pressure used to close the scram inlet and outlet valves. Air pressure is also provided to keep the scram discharge volume vent and drain valves open during normal operation.

7.3.5 PRA Insights

The Reactor Protection System (RPS) is a major contributor to core damage frequency for the ATWS cut set sequence. Failure of the RPS to perform its intended function would prevent a rapid reactor shutdown which if combined with other events could lead to core damage. This sequence is attributed to 2.9% of the core damage frequency at Hatch. The dominant failure for the RPS is due to mechanical faults of the system. The RPS was not modeled in any detail. RPS mechanical failure probability on demand was assigned a value of 1E-5. The failure probability used for mechanical was based on information provided in NUREG-0460. (i.e., the system was simply treated as a data value). The RPS failures have the highest risk reduction factor of all the BWR systems.

7.3.6 Summary

Classification - Safety related system

Purpose - To initiate a reactor scram to:

1. Preserve the integrity of the fuel cladding
2. Preserve the integrity of the reactor coolant system
3. Minimize the energy which must be absorbed following a loss of coolant accident

Components - Power supplies, logic, scram valve logic, scram valves

System Interfaces - All systems which provide parameter inputs, CRD system, Service and Instrument Air System, RMCS, Reactor Recirculation System

Table 7.3-1 Reactor Protection Scram Signals

Scram Signal	Signal Bypass	Probable Cause	Reason for Scram
Turbine Stop Valve Closure (<10% closed)	<30% Turbine First Stage Pressure	Any turbine trip	Protect Fuel Cladding against positive reactivity insertion following void collapse
Turbine Control Valve Fast Closure (500 psig ETS oil)	<30% Turbine First Stage Pressure	Generator Load Reject	Protect fuel cladding against positive reactivity insertion following void collapse
Scram Discharge Volume High Level (60 inches)	Keylock Switch in *bypass* and the mode switch in *shutdown* or *refuel.*	Leaking scram outlet valve(s) or any other scram has occurred.	Allows RPS to scram while the ability still exists
MSIV Closure (<10% closed)	Mode switch other than *run.*	MSIV closure signal	Protect fuel cladding against positive reactivity insertion following void collapse
High Drywell Pressure (1.69 psig)	NONE	Leak inside the Drywell	Protect Containment (minimize energy containment must absorb)
Low Reactor Water Level (12.5 inches)	NONE	Abnormal operational transient or pipe break.	Protect fuel cladding from inadequate cooling

Table 7.3-1 Reactor Protection Scram Signals (Continued 1)

High Reactor Pressure (1043 psig)	NONE	Abnormal operational transient.	Protect reactor coolant boundary integrity.
Main Steam Line High Radiation (3*normal)	NONE	Gross fuel cladding failure	Limit further fission product release from fuel
NMS-APRM Inop Trip	NONE	Flow channel inop; too few LPRM inputs; card unplugged; or switch misaligned	Protect fuel cladding integrity
Manual Scram Push Buttons	NONE	Scram buttons depressed	Allows manual scram whenever operator deems prudent

Table 7.3-1 Reactor Protection Scram Signals (Continued 2)

Scram Signal	Signal Bypass	Probable Cause	Reason for Scram
NMS-IRM High-High Trip (120/125 scale)	Mode switch in ***run*** except for IRM/APRM association	Failure to uprange IRMs or too short of a period.	Protect Fuel Cladding against excessive power and short periods
NMS-IRM Inop Trip	Mode switch in ***run*** except for IRM/APRM association	Low voltage; card unplugged; or switch misalignment	Protect fuel cladding integrity
NMS-APRM High-High Fixed Trip (15%)	Mode switch in ***run***	Abnormal operational transient	Protect fuel cladding against excessive power
NMS-APRM High-High Fixed Flux Trip (118%)	Mode switch other than ***run***.	Abnormal operational transient	Protect fuel cladding against excessive power
NMS-APRM High-High Flow Biased Thermal Trip (.66W+51% of rated power)	Mode switch other than ***run***.	Abnormal operational transient	Protect fuel cladding against excessive power
Mode Switch in *Shutdown*	When 10 second timer times out	Mode switch was placed in ***shutdown***.	Enforce shutdown conditions defined for shutdown mode.
NMS-SRM High-High	Shorting links installed	Fuel loading error	Protect fuel cladding integrity and personnel
NMS-SRM Inop	Shorting links installed	Switch misalignment; low voltage; or card unplugged	Protect fuel cladding integrity and personnel

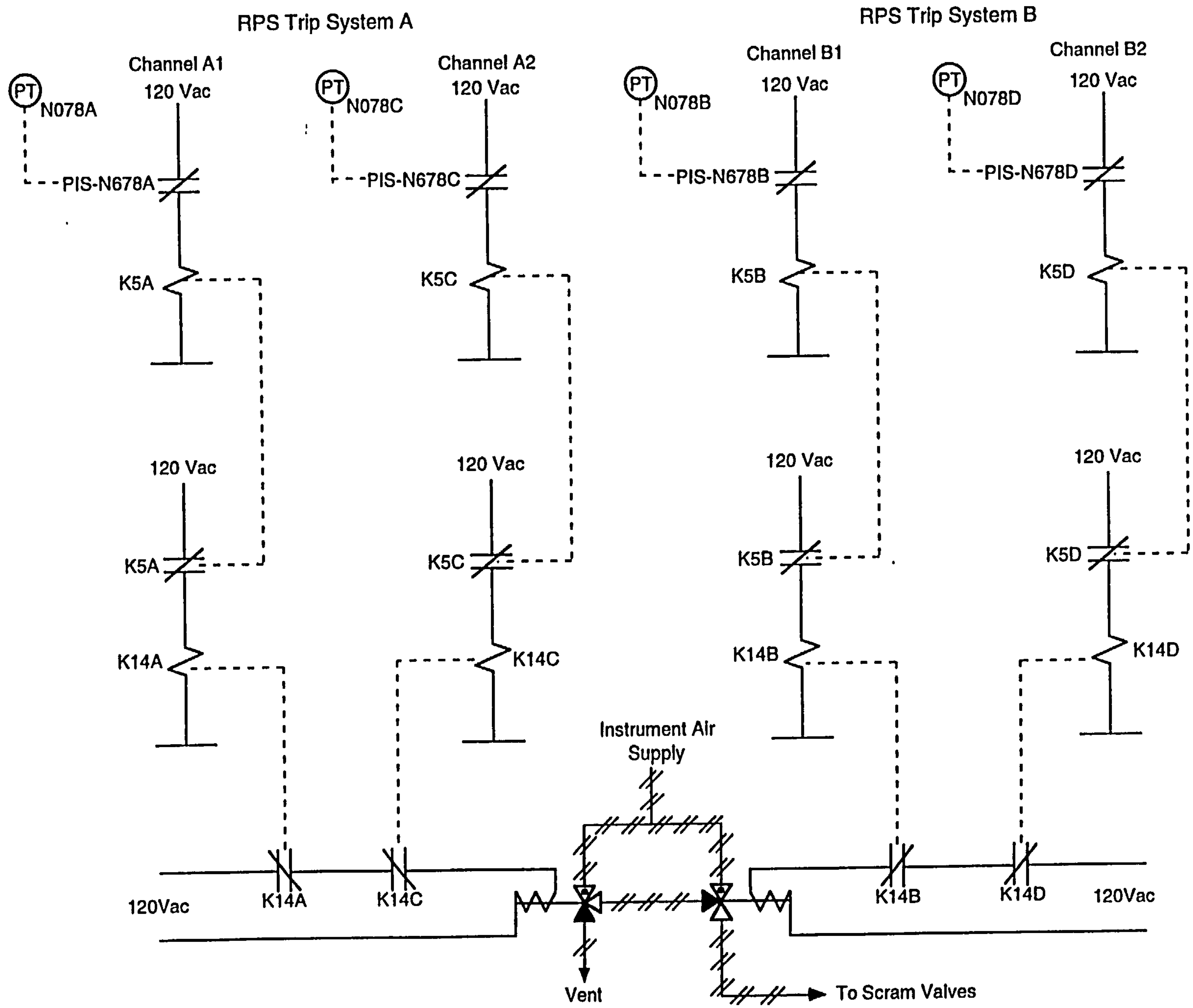
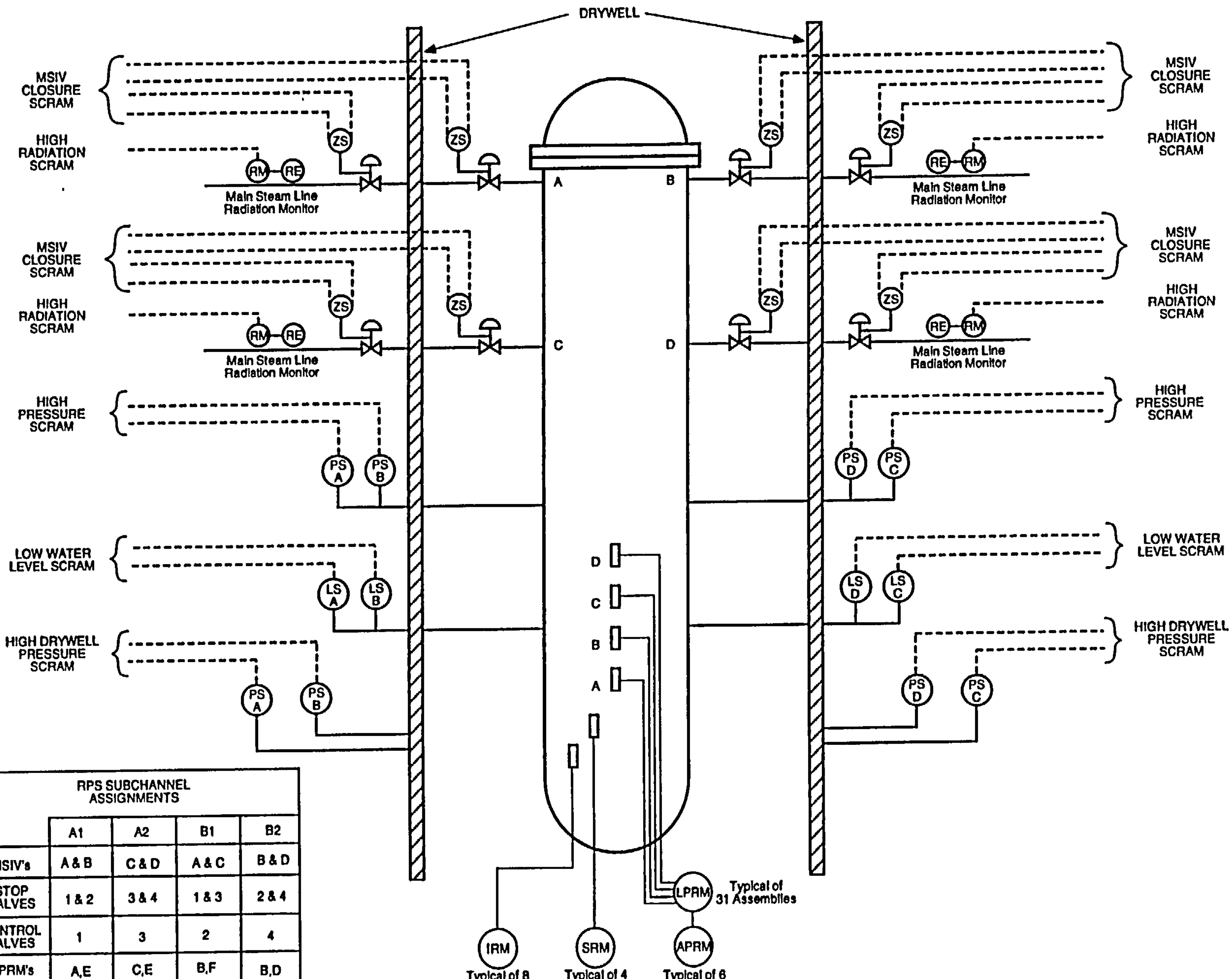
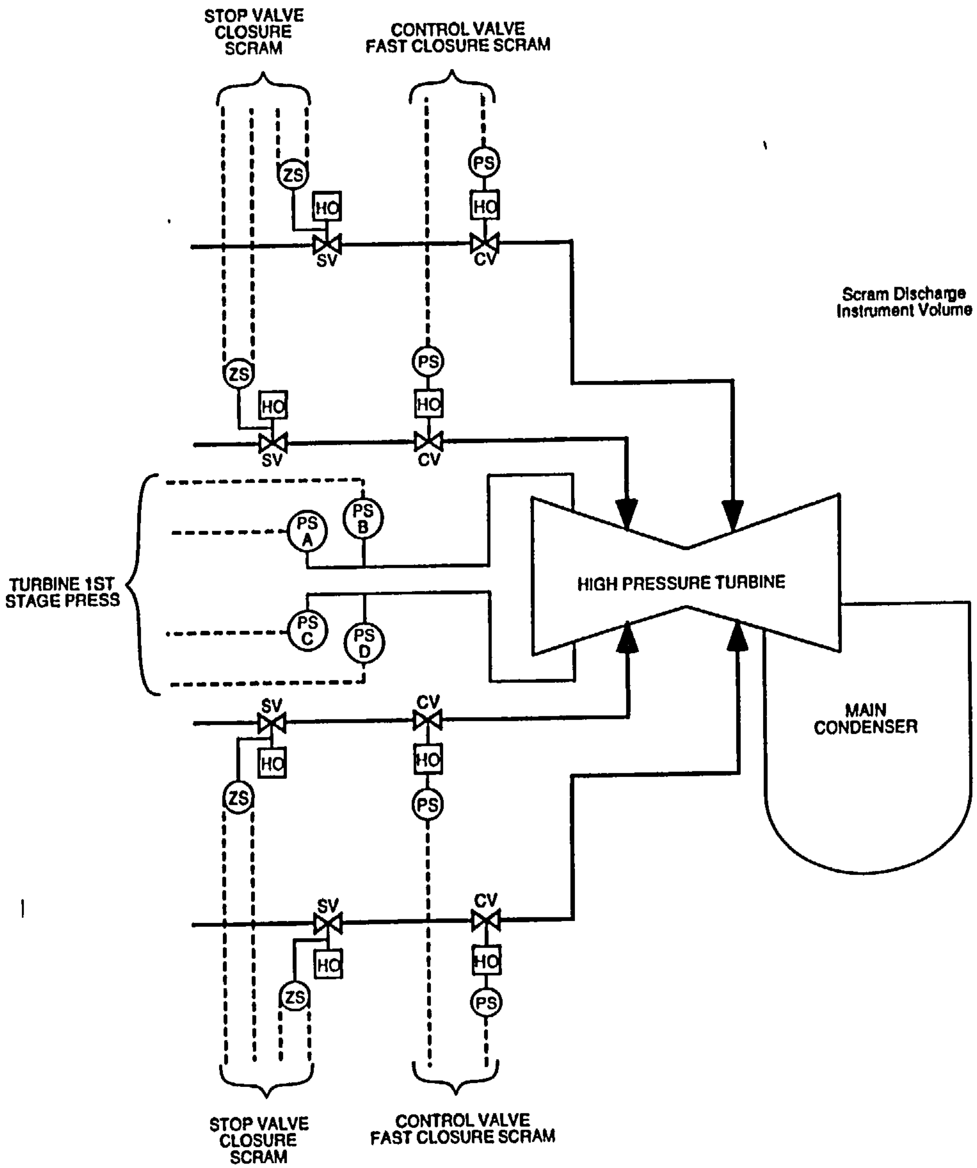


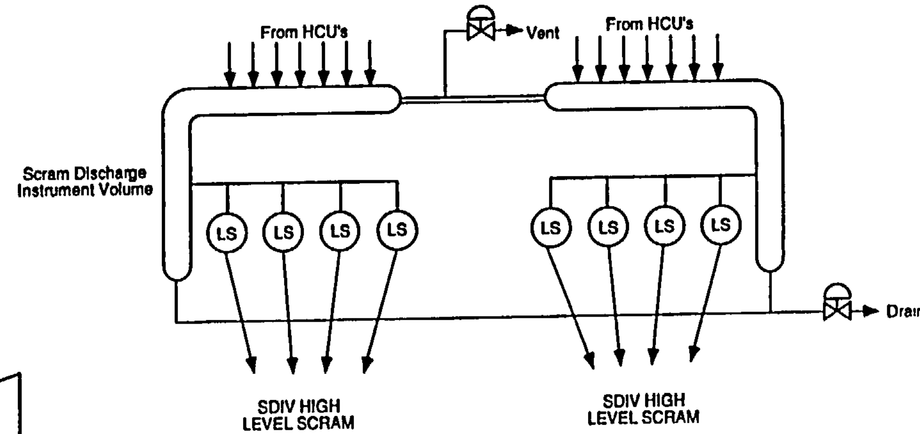
Figure 7.3-1 One Out of Two Twice Logic



RPS SUBCHANNEL ASSIGNMENTS	A1	A2	B1	B2
MSIV's	A & B	C & D	A & C	B & D
STOP VALVES	1 & 2	3 & 4	1 & 3	2 & 4
CONTROL VALVES	1	3	2	4
APRM's	A,E	C,E	B,F	B,D
IRM's	A,E	C,G	B,F	D,H

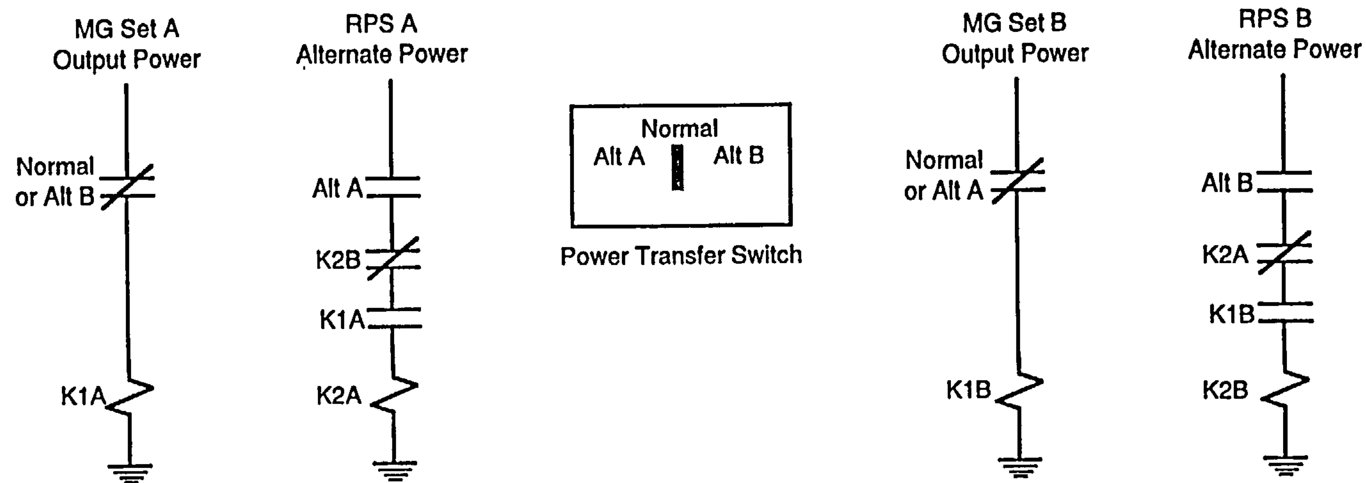
Figure 7.3-2 Reactor Protection System Sensors





RPS SUBCHANNEL ASSIGNMENTS				
	A1	A2	B1	B2
MSIV's	A & B	C & D	A & C	B & D
STOP VALVES	1 & 2	3 & 4	1 & 3	2 & 4
CONTROL VALVES	1	3	2	4
APRM's	A,E	C,E	B,F	B,D
IRM's	A,E	C,G	B,F	D,H

Figure 7.3-2 Reactor Protection System Sensors (Continued)



RPS Power Transfer Switch,
Relays, and Contacts

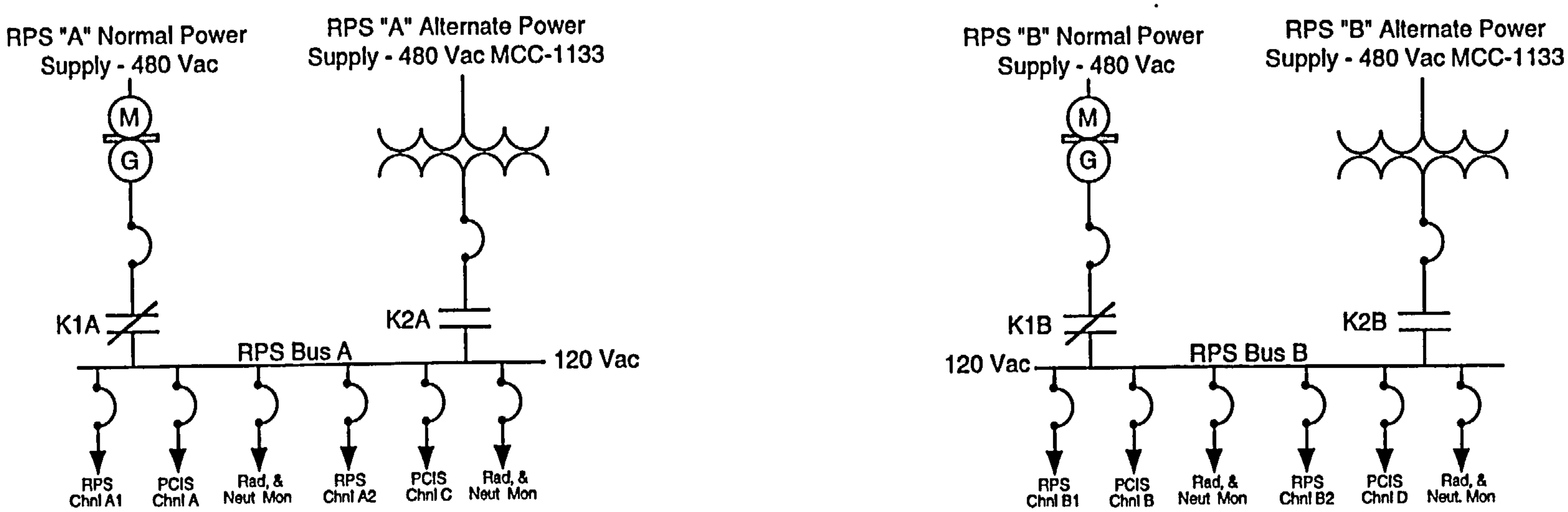


Figure 7.3-3 RPS Power Supply

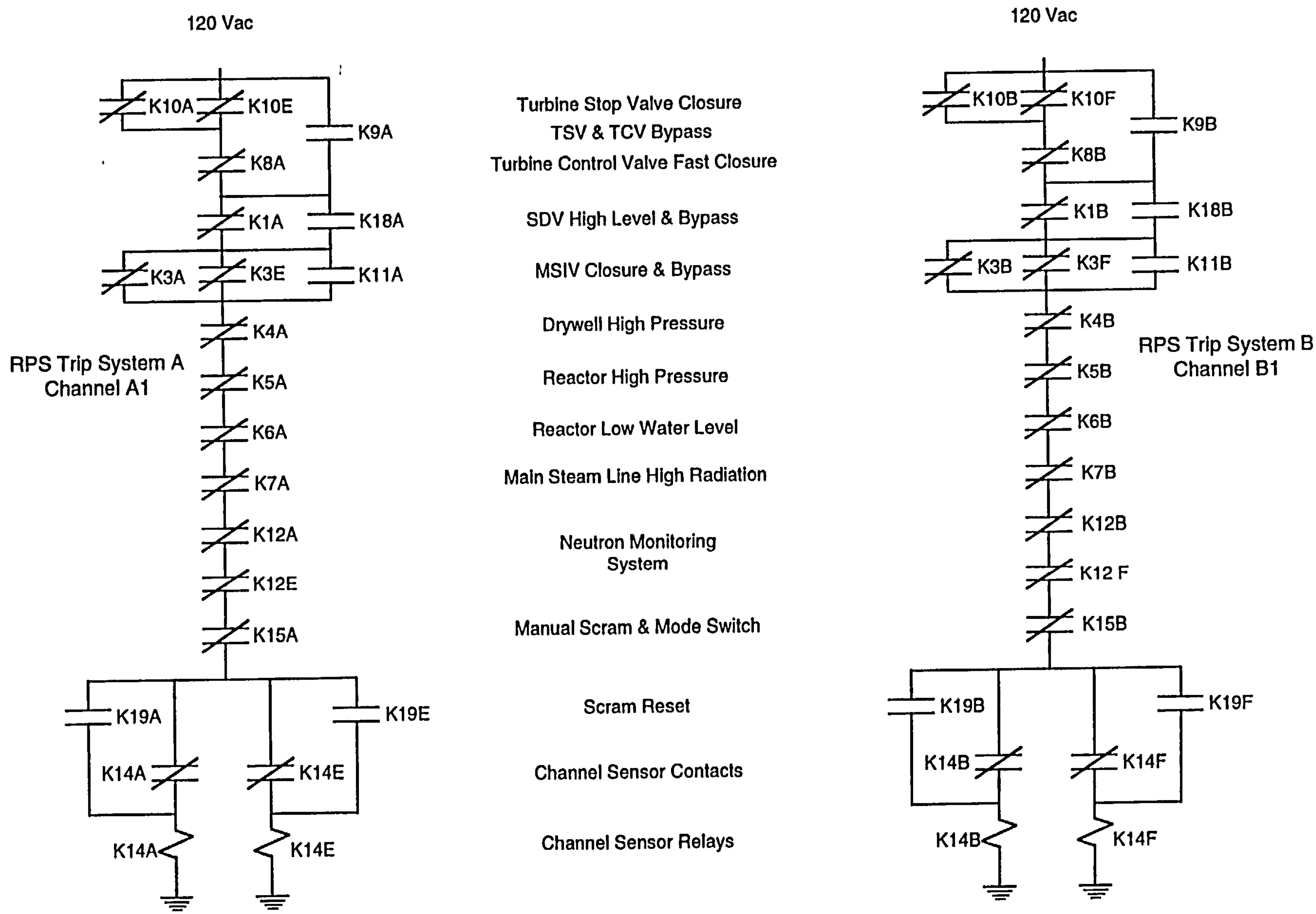


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Figure 7.3-4 RPS Trip System Logic

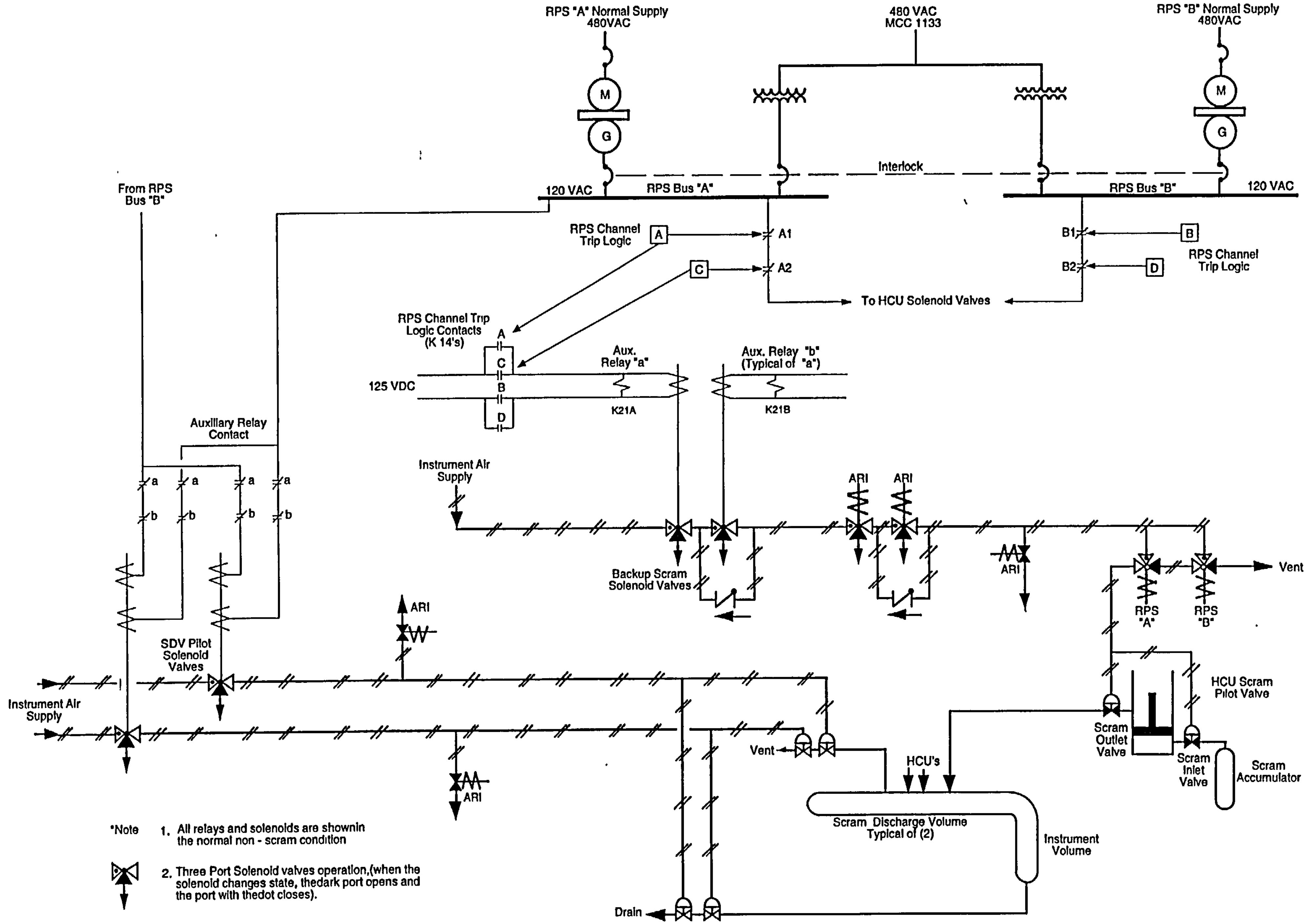

Figure 7.3-5 Simplified Reactor Protection System

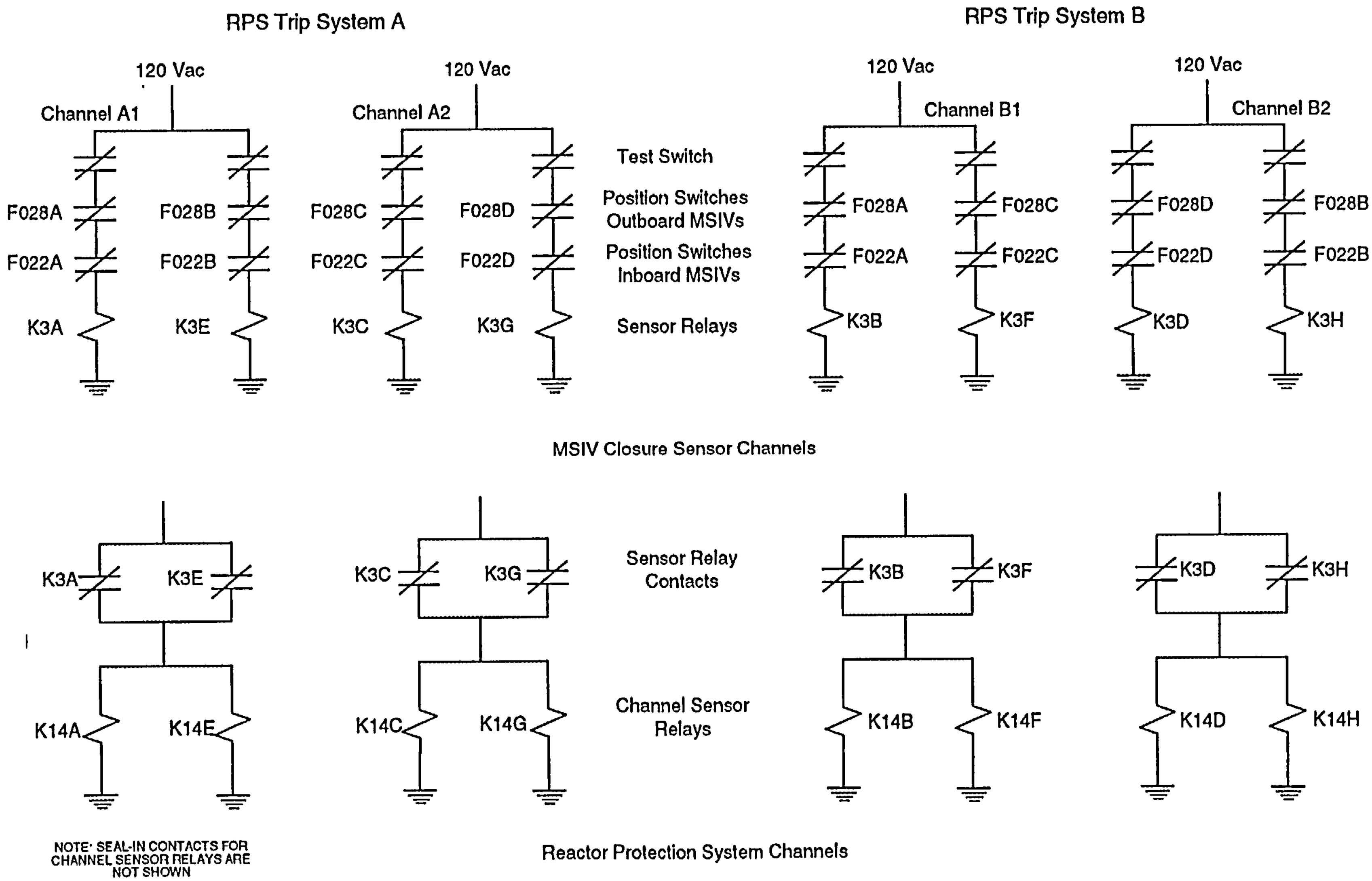

Figure 7.3-6 MSIV Closure Logic

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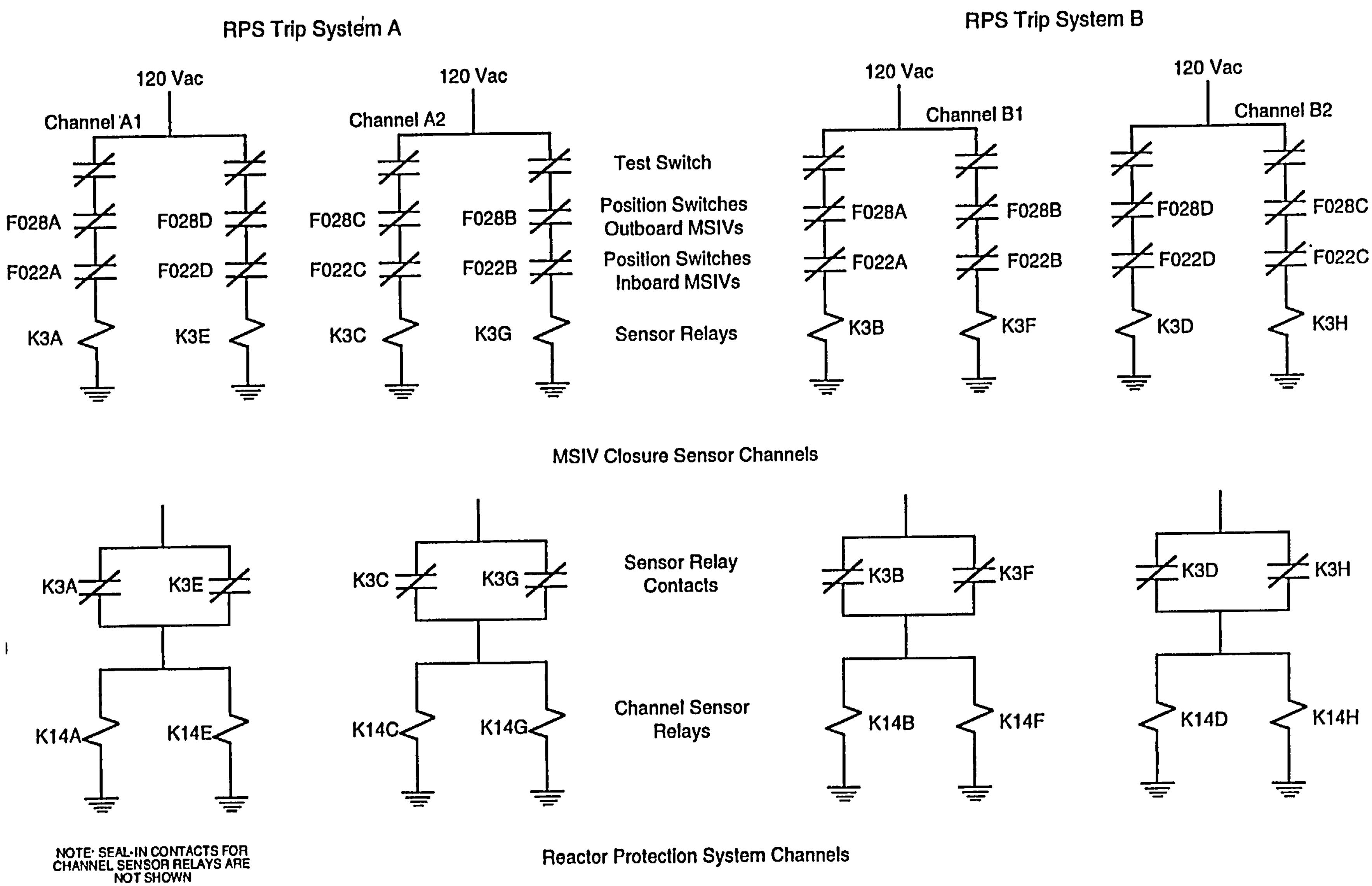

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Figure 7.3-6 MSIV Closure Logic

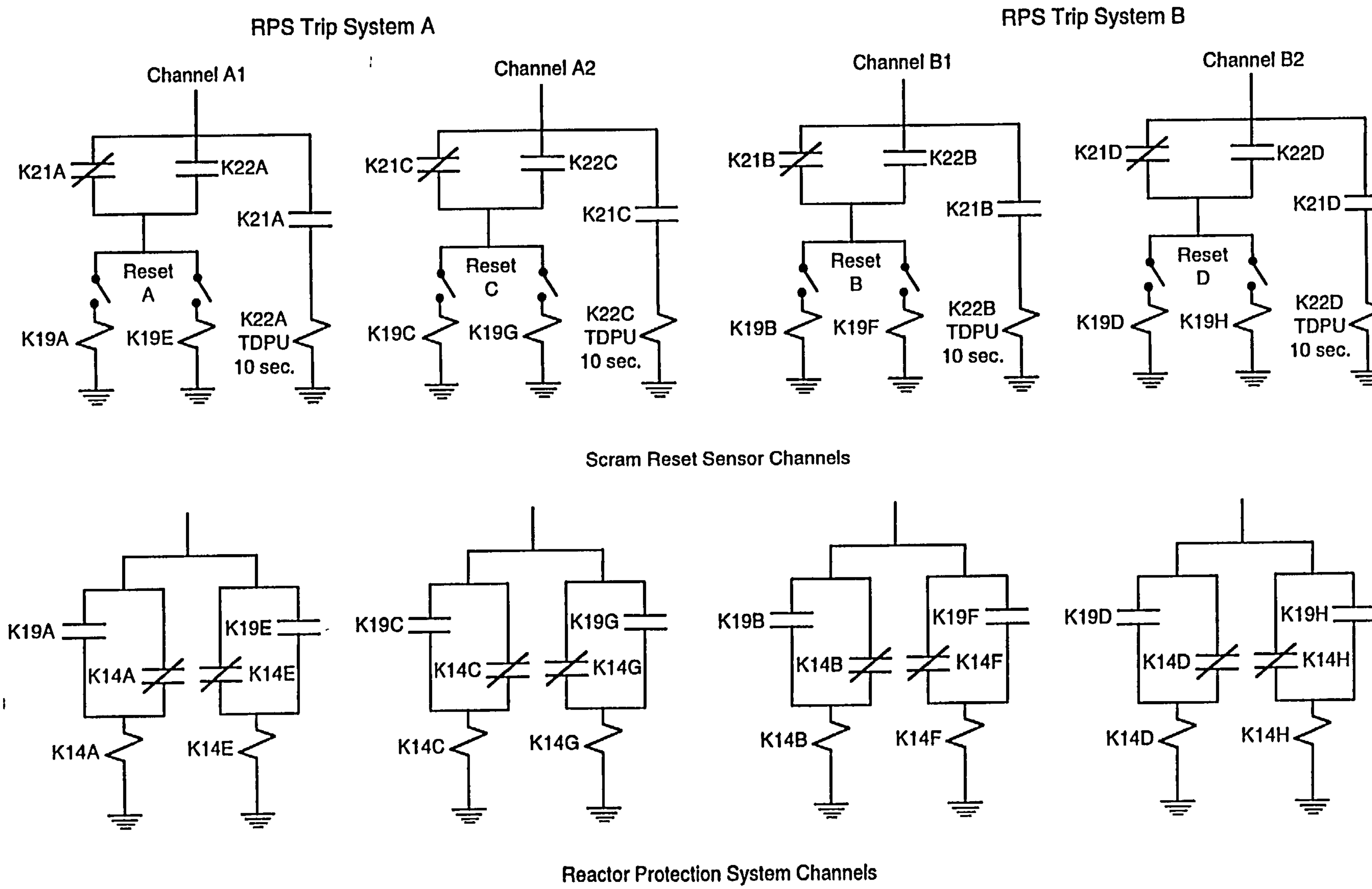

Figure 7.3-7 Scram Reset Logic

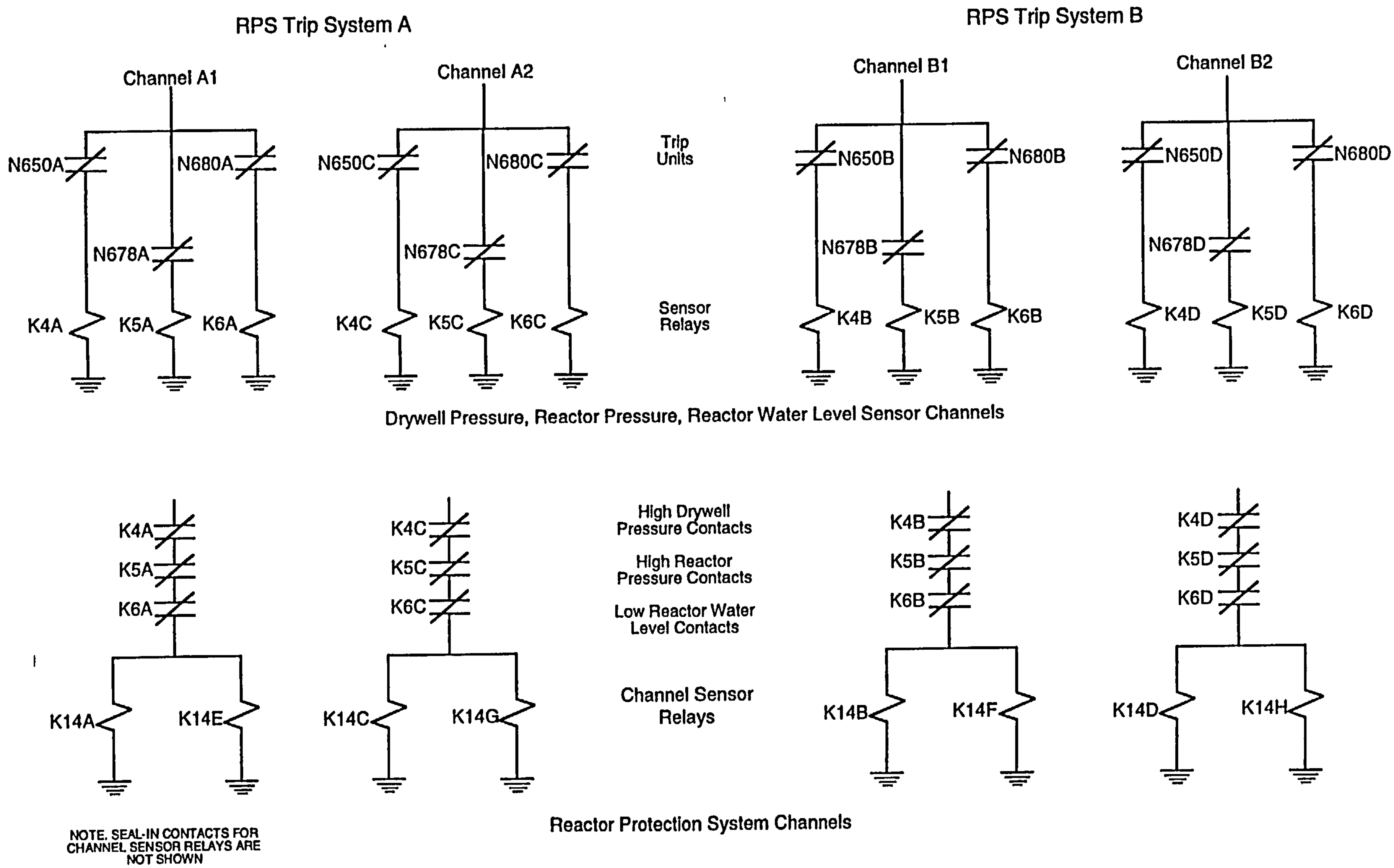

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Figure 7.3-8 High DW Pressure, High Rx Pressure, Low Rx Water Level Logic

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Chapter 7.4

Standby Liquid Control System

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7.4 STANDBY LIQUID CONTROL SYSTEM

Learning Objectives

1. State the system's purpose.
2. Explain how the system accomplishes its purpose.
3. Explain why the system lines are heat traced.
4. List the conditions that require manual initiation of the Standby Liquid Control System.
5. List the indications that can be used to verify initiation of the Standby Liquid Control System.
6. List the positive reactivity sources considered in the calculation of the minimum average boron concentration that is required to achieve the desired Shutdown Margin of 0.05% delta K/K.
7. Explain the purpose of the major system components:

   a. Storage tank
   b. Test tank
   c. Pumps
   d. Explosive valves
   e. Accumulators

7.4.1 Introduction

The purpose of the Standby Liquid Control (SLC) System is to inject enough neutron absorbing poison solution into the reactor vessel to shut down the reactor from full power, independent of control rod motion, and to maintain it in a subcritical condition as the plant operators cool the plant down to maintenance temperature.

The functional classification of the SLC System is that of a safety related system.

The Standby Liquid Control system, Figure 7.4-1, consists of a heated storage tank, two 100% capacity positive displacement pumps, two explosive actuated injection valves, and piping necessary to inject the neutron absorber solution into the reactor vessel. The system contains a sufficient quantity and concentration of neutron absorbing solution to shut down the reactor any time in core life without the use of control rods. In addition, the system includes a test tank with necessary valves and piping to adequately test the system without injecting poison into the reactor vessel.

The SLC System provides the operator with a relatively slow method of achieving reactor shutdown conditions. This system takes up to 36 minutes to inject all of the neutron absorbing solution after being manually started from the control room. The SLC System was never designed to serve as a backup for the reactor scram function of the Reactor Protection System (Section 7.3)

7.4.2 Component Description

The major components of this system are discussed in the paragraphs which follow and are illustrated in Figure 7.4-1.

7.4.2.1 Storage Tank

The standby liquid control storage tank is a stainless steel tank with a working capacity of 4,850 gallons. The tank size was based on the old volume requirements prior to the use of enriched boron-10. The tank provides the means for storage and mixing of the neutron absorber solution. Two immersion heaters are installed near the bottom of the tank to prevent the neutron absorber solution, sodium pentaborate, from precipitating out of solution. To increase the solubility, the manually operated mixing heater raises the temperature to 150°F whenever chemicals are added. The thermostatically controlled heaters are automatically controlled to regulate the solution temperature at 80 +10°F. Both heaters are powered from the Emergency AC Power System.

Air is supplied to a sparger with six branch lines inside the tank for proper boron solution mixing. Makeup water is supplied to the tank from the Demineralized Water System. A removable hatch is located on the top of the tank to provide access for chemical addition and sampling. A vent and overflow line from the tank is directed to a collection sump.

7.4.2.2 Standby Liquid Control Pumps

The sodium pentaborate solution is pumped into the reactor vessel by either of two 100% capacity, triplex piston, positive displacement pumps. Each pump is designed to deliver the neutron absorbing solution to the reactor vessel at a flow rate of 41.2 gpm against a back pressure of 0-1250 psi. Normal control of the pumps is from the control room via a single selector switch. Local switches are also provided for testing purposes. The local switches bypass the explosive valve ignition circuitry and allow the running of both pumps.

7.4.2.3 Explosive Valves

The explosive valves (Figure 7.4-2), one for each pump, are located between the discharge of the SLC pumps and the reactor vessel. Location of the valves ensure the failure of a single valve will not prevent the SLC system from performing its function. Each valve is a double squib actuated shear plug, zero leakage valve. When either explosive squib is fired, it drives a ram forward to shear off the integral cap of the inlet fitting. The extended ram prevents the shear plug from obstructing flow through the valve by forcing it into a recess in the valve body. The products of the explosion are completely retained in the primer chamber and cannot contaminate the boron solution passing through the valve.

Removable spool pieces in the piping immediately upstream of each valve facilitate replacement of the shear plug. Upon initiation of one of the SLC pumps both of the explosive valves will fire. When either pump is started, from the control room, a command current greater than 2 amperes is applied to one of the two primers in each explosive valve.

When the SLC system is in its normal standby condition, a continuous, no fire current, approximately 1 milliamp maximum, is passed through the bridge wire network in the trigger assembly of each explosive valve. This trickle current ensures continuity of the firing circuit which can be used to ensure operability of the valve.

7.4.2.4 Test Tank

The test tank provides a means for system testing and flushing with demineralized water. The stainless steel cylindrical tank has a nominal capacity of 210 gallons. Makeup water to the tank is provided from the demineralized water system. The tank can only be drained to a collection drum via the test tank drain valve.

7.4.2.5 Vessel Injection Line

The vessel injection line serves a dual function within the reactor vessel. It provides an injection path for the sodium pentaborate solution and a tap for vessel instrumentation. The injection line contains two check valves in series, located on either side of the drywell penetration and a normally open manual isolation valve. The manually operated isolation valve is locked in the open position and contains position indication switches that indicate open/close position in the control room. The injection line enters the reactor vessel at a point below the core shroud as two concentric pipes (Figure 7.4-3). In the lower plenum, the two pipes separate. The inner pipe terminates near the core shroud with a perforated length below the core plate. The inner pipe is used to sense below core plate pressure and to inject liquid control solution when required. The outer pipe is used to sense core plate pressure for core delta P indication, CRD System vessel pressure measurement, and core spray line break detection. The use of two pipes, reduces the thermal shock to the reactor vessel when the SLC is started.

7.4.2.6 Drain Piping

The use of drain piping from the pump suction cross connect line, pump base plate, pump discharge cross connect pipe, and the test tank preclude the necessity of heat tracing pipe to the radwaste system. The drains are all piped to a 55 gallon drum. By draining all of the potentially borated water to a 55 gallon drum the radwaste system does not have to process borated waste.

7.4.2.7 Neutron Absorbing Solution

The sodium pentaborate neutron absorber solution is a mixture of borax, boric acid, and demineralized water. The borax has been enriched with B-10 content to approximately 85%. Naturally occurring Boron is composed of two isotopes (Boron 10 and Boron 11), with Boron 10 abundance at approximately 20%. Eagle Picher Industries supplies enriched Boron (90%) in the form of sodium pentaborate decahydrate ($Na_2 \cdot 5B_2O_3 \cdot 10H_2O$), which is a white granular powder. The sodium pentaborate decahydrate has a shelf life of 40 years.

By increasing the Boron 10 content the tank liquid volume was reduced from the original design in addition to a faster shutdown time. Adoption of the Anticipated Transients Without Scram (ATWS) rule 10CFR 50.62, required an increased injection capability: Each BWR must have a SLC system with a minimum flow capacity and boron content equivalent to a control capacity of 86 gpm 13 weight percent sodium pentaborate solution, (natural Boron enrichment). The ATWS rule was established to reduce the risk from anticipated transients without scram events. The injection rate for a 218 in. diameter vessel assuming a minimum sodium pentaborate concentration of 12% and a small allowance for pump degradation was 76 gpm. To meet the rule the options became to either use two pumps or use enriched boron.

An increased concentration was used by this plant. Calculation of the ATWS rule required an enrichment of approximately 40 atom percent of B-10 in sodium pentaborate be utilized if a single pump injection rate of 43 gpm is maintained. By utilizing a 90 atom percent B-10, at the current pumping rate of 41.2 gpm, a reduction in the core melt frequency is realized along with a capability 2.06 times the ATWS rule requirement. The use of highly enriched sodium pentaborate reduces the required net tank liquid volume to approximately 25% of the original volume. Using enriched solution also allowed for a reduction in the maximum concentration limits from 13.8% (natural boron) to 12.0% (enriched sodium pentaborate). The 12.0% corresponds to a lower saturation temperature

(54°F) thereby reducing the required operating heater duty.

The original SLC systems design bases, prior to the ATWS rule, required injection of sodium pentaborate solution into the reactor core such that an analytically equivalent concentration of 660 ppm of natural boron exist at level 8, with the RHR system in shutdown cooling mode and at 70°F. Included was an additional 165 ppm to allow for imperfect mixing. Combined this added up to 825 ppm. The enriched boron changed these concentration requirements from 825 ppm cold shutdown to 193 ppm of 85 atom percent enrichment.

7.4.3 System Features and Interfaces

A short discussion of system features and interrelations between this system and other plant system is given in the paragraphs which follow.

7.4.3.1 Controls and Indications

The controls and indications for the SLC system are located in the control room. The SLC system is initiated by a single key lock switch to ensure positive action is required for actuation.

7.4.3.2 Normal Standby Mode

The SLC system must be maintained in an operational standby status when there is fuel in the reactor vessel and the reactor is operating, as required by Technical Specifications. In the standby mode of operation the SLC system is lined up as indicated in Figure 7.4-1.
The SLC storage tank is maintained between the high and low level alarm points with the required amount of sodium pentaborate solution per Technical Specifications. In addition the storage tank and piping are maintained at their required temperatures to prevent the solution from solidifying.

7.4.3.3 Injection Mode

The SLC system is actuated by a key-locked switch on panel 603 in the control room. If the operator determines that neutron absorber solution should be injected into the reactor per Emergency Operating Procedures, a key must be inserted into the switch and the switch turned to the system A or system B position. Turning the switch to system A, starts the A pump, fires both explosive valves, and isolates the Reactor Water Cleanup System. The system B position duplicates the A except for starting a different pump.

Redundant explosive valve firing circuits allow either system to fire both valves. Positive indication of system injection is provided by all of the following:

1. Pump on light for the system started
2. Loss of continuity light and alarm
3. Pump discharge pressure
4. Storage tank level decreasing
5. Reactor power decreasing

7.4.3.4 Pump Flow Rate Test

The pump flow rate testing is performed, at the pumps, via start and stop switches to prevent firing of the squib valves on pump start and injecting water into the reactor vessel. The pump suction is aligned to the test tank, which contains demineralized water. Pump discharge is aligned to a drain, via a hose attached to the discharge line vent. After alignment is made one of the SLC pumps is started and the discharge vent valve is throttled to simulate reactor pressure of 1150 psig. Following the adjustment of pump discharge pressure the pump is secured and the test tank is filled with demineralized water. The pump is started again, locally, and the time required to pump the test tank down to a predetermined level is measured. By measuring the time to pump down a known volume of water, the capacity of the pump can then be calculated in gallons per minute.

7.4.3.5 System Actuation Testing

System actuation testing is performed once a cycle with the reactor shutdown. During this test, demineralized water from the test tank is pumped into the reactor vessel to verify pump discharge capacity and the performance of the explosive valves. Prior to initiation the test tank is filled and aligned to the SLC pump suction. The system is then flushed using the demineralized water. One explosive valve is then electrically disarmed. The test is then initiated from the control room, to check actuation of the armed explosive valve and the ability to pump water into the reactor vessel. Following the test, the system is realigned for standby conditions, including replacement of the fired squib shear plug assembly.

7.4.4 System Interfaces

A short discussion of interfaces this system has with other plant systems is given in the paragraphs which follow.

7.4.4.1 Reactor Vessel System (Section 2.1)

The SLC System injects the neutron absorbing solution into the reactor vessel through a penetration in the bottom section of the vessel.

7.4.4.2 Reactor Water Cleanup System (Section 2.8)

The initiation of the SLC system automatically isolates the RWCU System to prevent poison removal.

7.4.5 Summary

Classification - Safety related system

Purpose - To shutdown the reactor by chemical poisoning in the event of failure of the control rod drive system.

Components - Storage tank; 2-100% capacity pumps; 2-100% capacity explosive valves; injection pipe; test tank.

System Interfaces - RWCU System; Reactor Vessel and Internals; Service and Instrument Air; Demineralized Water System.

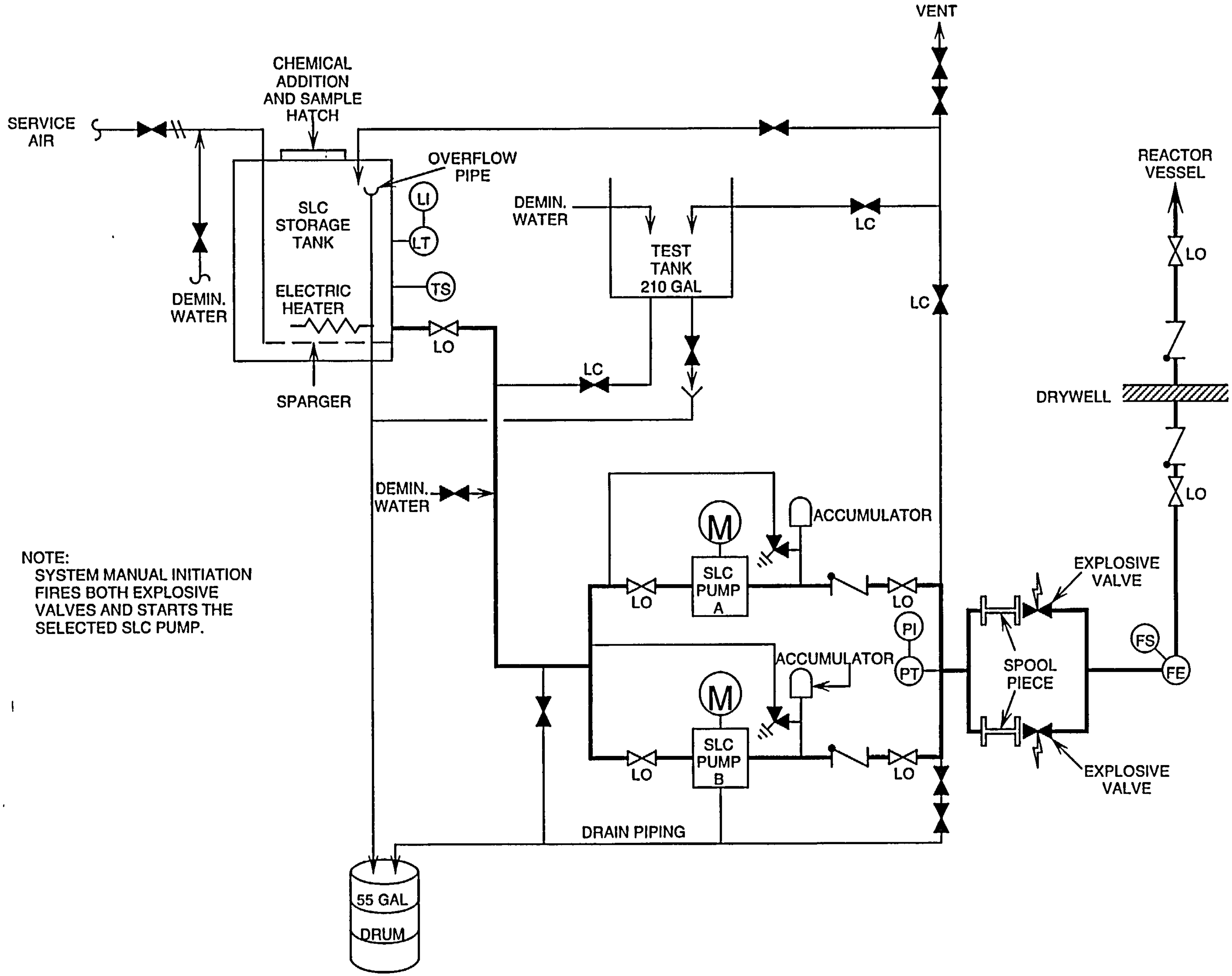

Figure 7.4-1 Standby Liquid Control System

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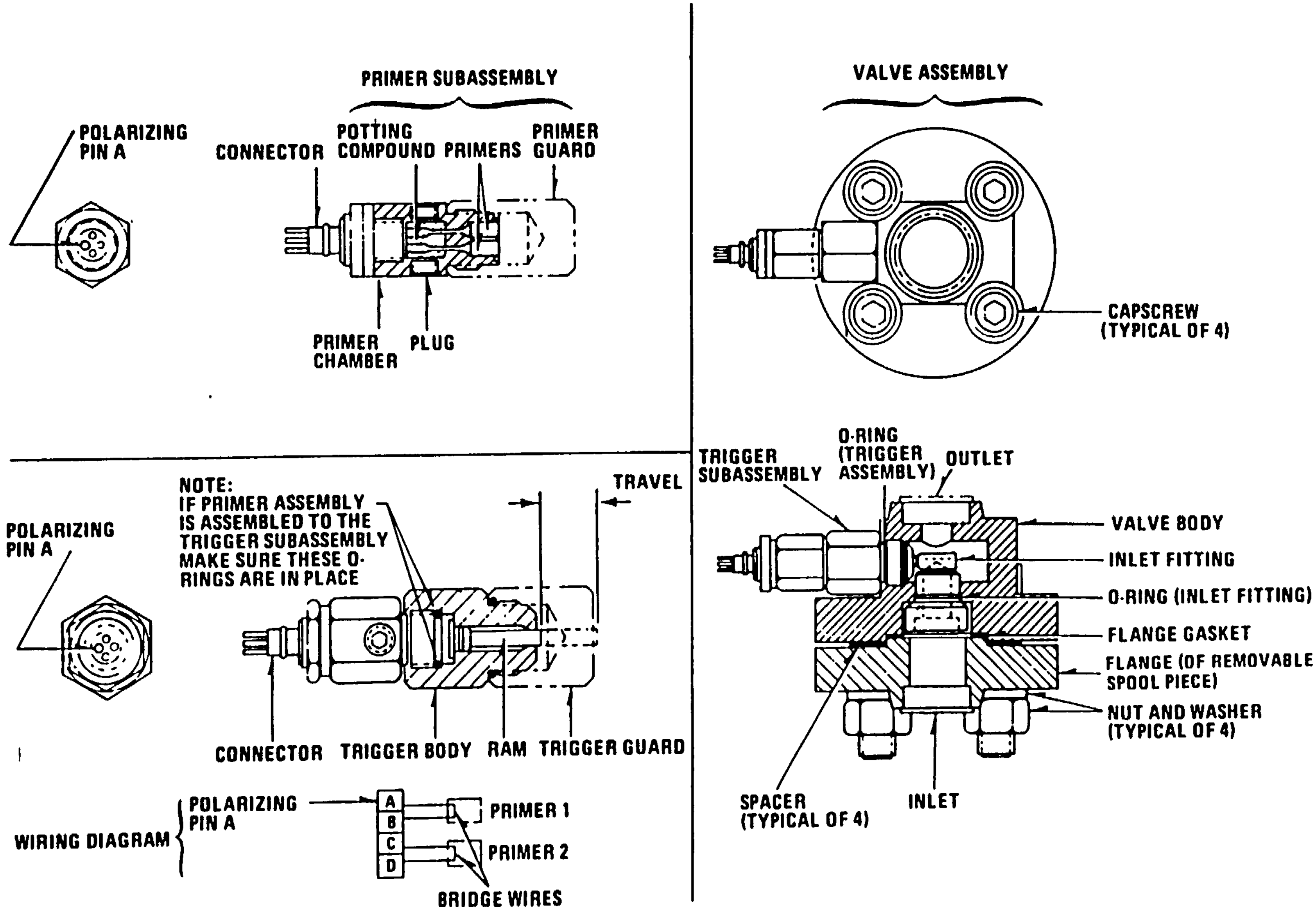

Figure 7.4-2 Explosive Valve (Cross-Sectional View)

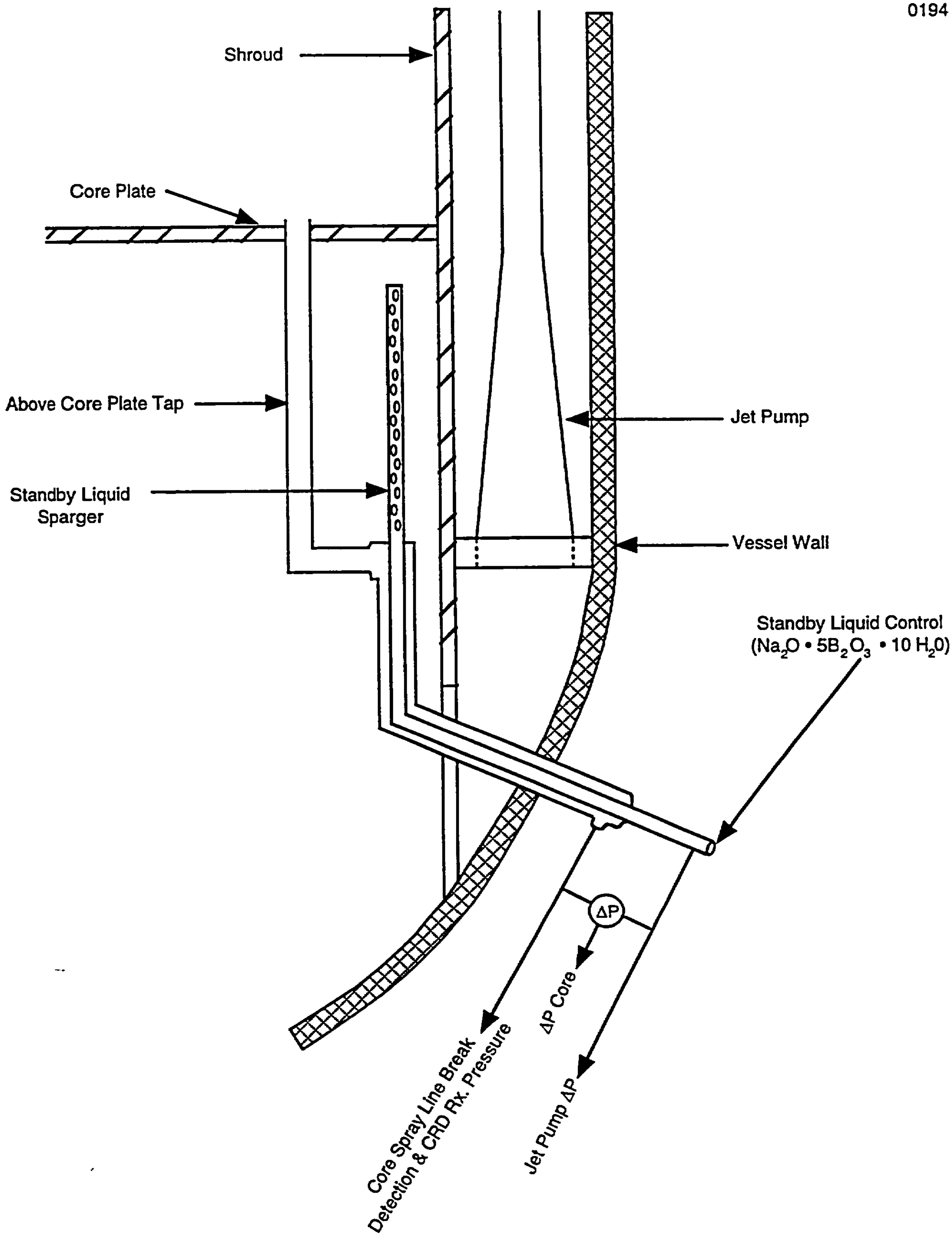

Figure 7.4-3 Standby Liquid Control Sparger Layout

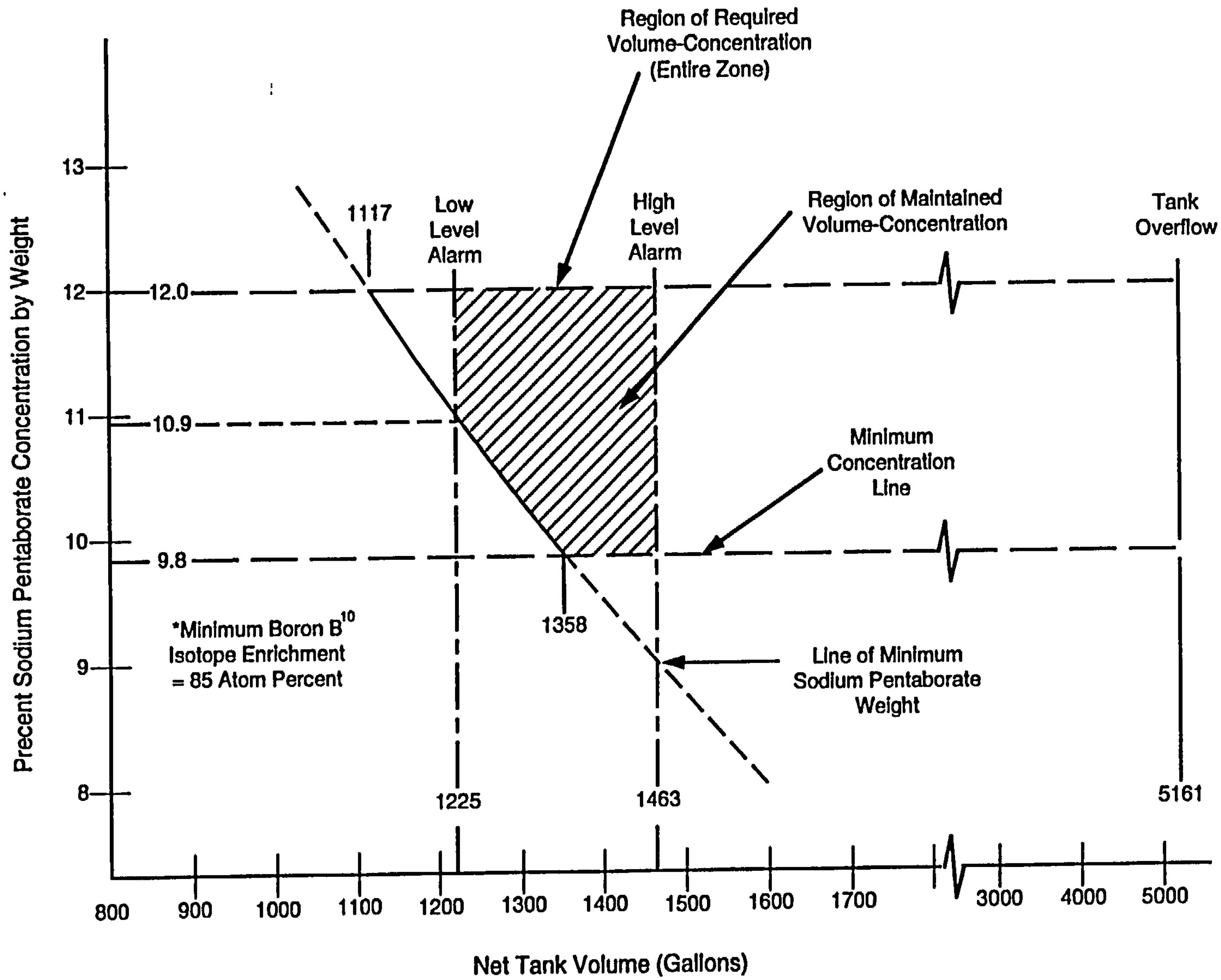

Figure 7.4-4 Sodium Pentaborate Solution Concentration vs. Net Tank

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Chapter 7.5

Rod Worth Minimizer System

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7.5 Rod Worth Minimizer

Learning Objectives

1. State the System's purpose.
2. List the rod blocks imposed by the RWM.
3. Define black/white control rod pattern.
4. Define the following terms.
   a. Low Power Alarm Point
   b. Transition zone
   c. Low Power Set Point
5. Explain how this system interfaces with the following systems:
   a. Main Steam System
   b. Reactor Manual Control System
   c. Process Computer

7.5.1 Introduction

The purpose of the Rod Worth Minimizer (RWM) is to serve as a backup to procedural controls and to limit rod worth during low power operation.

The functional classification of the Rod Worth Minimizer is that of a safety related system.

The Rod Worth Minimizer assists and supplements the operator with a control rod monitoring routine that enforces adherence to established startup, shutdown, and low power level control rod sequences. The computer prevents the operator from establishing control rod patterns that are not consistent with the prestored RWM program by initiating appropriate rod withdrawal and/or insert block interlock signals to the Reactor Manual Control System. The RWM sequences stored in the computer memory are based on controlling rod worth at acceptable levels, determined by the design basis rod drop accident. Actual control rod positions are obtained for comparison to the sequence from the control rod position information probes.

The Rod Worth Minimizer does not interfere with normal reactor operation, and in the event of a failure will not cause rod patterns to be established which would violate the above objective. The RWM function may be bypassed and its rod block function disabled only by specific procedural control initiated by the operator.

7.5.2 Component Description

The major components of this system are discussed in the paragraphs which follow.

7.5.2.1 RWM Program

To understand the RWM program, definitions of the terms used in the program will be given, followed by a description of the sequence enforcement by the RWM.

Operating Sequence

An operating sequence is a schedule to be followed by the plant operator when withdrawing or inserting control rods. Two sequence schedules, known as Sequence A and Sequence B, are prepared and printed out for the operator's use when starting up or shutting down the reactor. One of the sequences is read into computer memory for use by the RWM program. Each sequence identifies the control rod, by XX-YY coordinates, and the positions, even numbers between 00 and 48, to which each rod should be positioned. When decreasing power, the control rods are inserted in the reverse order of their withdrawal. Although the sequences may vary depending on individual reactor size and characteristics, each generally begins by withdrawing 50% of the control rods to the full out position. Under cold conditions, this brings the reactor to the point of criticality and into the heating range. The control rods fully withdrawn are distributed in a checkerboard pattern (black/white) across the core cross section, such that every other rod along either an X or Y coordinate will be withdrawn as shown in Figure 7.5-2. This pattern is also referred to as 50% rod density, where rod density is the percent of notches fully inserted. The remaining rods are then withdrawn to either full out or intermediate positions in the order specified by the sequence being used to bring the reactor up to full power. Sequence A and Sequence B differ in that those rods which are fully withdrawn when the reactor is brought to 50% rod density using Sequence A are the rods which remain inserted when the reactor is brought to the same point by Sequence B. In addition, the distribution of rod positions attained as rods are withdrawn after 50% rod density are also different for the two sequences. Using one sequence will result in operation of the reactor in the rotational symmetry mode while use of the other sequence results in the mirror symmetry mode of operation. The two sequences and their associated operating modes are changed at specified intervals during a fuel cycle to maintain optimum core power distribution and uniform fuel depletion across the core. Figures 7.5-3 and 7.5-4 illustrate a typical sequence A and will aid in the understanding of various terms.

Rod Groups

Rod groups are the sequential subdivisions of an operating sequence. A group consists of a number of specified control rods, from one to a dozen or more, and a set of insert and withdraw positions limits. The groups are numbered sequentially from the all rods in condition to 100% power. For example, group 1 of sequence A contains rods to be withdrawn first during a reactor startup and the last rods to be inserted during a shutdown. The insert limit for this group is therefore position 00 and the withdraw limit is position 48. When all the rods in group 1 have been withdrawn to the group 1 withdraw limit, the operator proceeds to group 2. Thus at any point in the sequence, assuming the sequence has been strictly followed, all the rods in group 1 through group i-1 should be at the withdraw limit for their respective groups, while all the rods in group i+1 through the highest numbered group are at their insert limits. After the black/white rod pattern has been achieved, end of group 4, the span between the insert and withdraw limits for higher groups generally becomes considerably smaller. Therefore, control rods may appear in more than one rod group. In this case, the withdraw limit for a rod appearing in a given group will be the same as the insert limit for the same rod in the next higher group in which it appears.

Latched Group

The latched group is the highest numbered group within the operating sequence compatible at a given time with the existing distribution of control rod positions. As control rods are being moved to raise or lower reactor power level, latching of the next higher group is done internally by the RWM program. Conversely, the program will latch the next lower group when all the rods in the presently latched group have been inserted to the group insert limit. The program latches the next higher group when all the rods in the currently latched group and in all lower groups, save two rods, have been withdrawn to their respective group withdraw limits.

Low Power Set Point

The Low Power Set Point (LPSP) is the core average power level below which the RWM program is active in forcing adherence to the operating sequence of rod withdrawals or insertions. When the core power level is above the LPSP, the RWM program does not impose rod blocks as a result of rod movement by the operator. The operating sequence ceases to be enforced above the LPSP. The LPSP is set above the level of required enforcement (20%) and is sensed by total steam flow being greater than 20% of rated.

Low Power Alarm Point

The Low Power Alarm Point (LPAP) is the core power level above which all RWM alarms, and error displays are discontinued. The low power alarm point setting is set at a total steam flow of 30% of rated flow.

Transition Zone

Transition Zone is the name given to the range of reactor power levels above the low power set point but below the low power alarm point. When the reactor is operating in this range, the RWM does not enforce the operating sequence, but the system alarms and displays errors that update every five seconds. This allows the operator time to identify and correct errors before the RWM begins enforcing the restraints.

Withdraw Error

A withdraw error can occur either when a rod contained in the currently latched group or any lower group is withdrawn past the withdraw limit for the group. In addition, if a control rod in a group higher than the currently latched group is withdrawn past the insert limit for the higher group.

Insert Error

An insert error occurs when a rod contained in the currently latched group is inserted past the insert limit or if a rod contained in a lower group is inserted past its withdraw limit.

Select Error

A select error occurs when a control rod is selected in other than the currently latched group. The select error provides the operator with warning that he has selected a rod that will result in an insert/withdraw error if moved. An alarm light on the RWM operator's panel is lit when a select error is made.

Withdraw Block

The RWM withdraw blocks are imposed to enforce correction of existing errors before allowing further control rod movement. A control rod withdraw block is imposed by the RWM program whenever:

1. A single withdraw error has been made.
2. An insert block has been imposed by the RWM. This block applies to any control rod selected for movement except existing insert errors.

Insert Block

The RWM insert blocks are imposed to enforce correction of existing errors before allowing further rod movement. A control rod insert block is imposed by the RWM program whenever:

1. A third insert error is made. Applies to all control rods.
2. A withdraw block has been imposed by the RWM and the operator selects a rod other than the existing withdraw errors.
3. A notch error is made and the operator selects a control rod that will not correct the notch error.

Nominal and Alternate Group Limits

In addition to the nominal insert and withdraw limits for each control rod group, a set of alternate insert and withdraw limits are include in the RWM software program. The alternate limits are used by the RWM program to determine insert errors only. To illustrate, assume that the nominal withdraw limit for a given rod group is specified as position 26. The alternate withdraw limit for this group will then be position 24. Any rod left at position 24 would not be treated as an insert error during a withdraw sequence. The same holds true for alternate insert limits, with the exception of groups having a nominal insert limit of 00. For these groups, the alternate insert limit is position 02.

Assignment of these alternate limits is well within the RWM design specifications which allows for a tolerance of ±2 notch positions on the nominal limits. Since the RWM program will consider a rod to be at the group limit when it is in either the nominal or alternate limit position, the addition of alternate limits materially reduces the chances that the program will generate unnecessary rod blocks due to failure of a rod position sensor at one of the group limit positions.

As a further safeguard against rod position sensor failure, the RWM program will automatically accept a substitute rod position for a rod which RPIS data is bad, if the operator has stored this information in the process computer memory.

7.5.2.2 RWM Operators's Panel

All the operating controls and indicators for the rod worth minimizer are located on the RWM operator's panel. The RWM controls and indications are illustrated in Figure 7.5-5. Discussions of the various controls and indications are in the paragraphs that follow.

Insert Error Digital Display Windows

These two four-digit displays are used to identify control rods responsible for causing insert errors. The XX-YY coordinates of the error rod(s) are displayed in the two upper windows. The rod, which causes the first insert error encountered by the program is identified in the upper most left window. An additional insert error will be posted in the next lower window. Both windows are blank if no insert errors exist or if the RWM is bypassed manually or automatically.

Withdraw Error Digital Display Window

This four-digit XX-YY display is used to identify a control rod responsible for a withdraw error. The withdraw window is blank if no withdrawl errors exist or if the RWM is bypassed manually or automatically.

Rod Group Digital Display Window

The rod group two-digit display window displays the group number of the rod that is currently latched. The window is blank when the RWM is bypassed.

Select Error Light

The select error indicating light illuminates amber whenever a control rod is selected which is not contained in the currently latched rod group. In addition, it will also illuminate if the selected rod is not an error rod responsible for an existing rod block.

Insert Block Light

The insert block display light illuminates red whenever an insert block is applied by the RWM program.

Withdraw Block Light

The withdraw block display light illuminates red whenever a withdraw block is applied by the RWM program.

Manual Bypass Light

The manual bypass display light illuminates amber when the RWM is manually bypassed by the operator.

Auto Bypass Light

The automatic bypass display light illuminates amber when the RWM is bypassed automatically by the steam flow signal.

Normal-Bypass Keylock Switch

The Normal-Bypass switch is used to manually bypass the RWM function. The switch is maintained in the normal position, key removed. To bypass the RWM, when the RWM program is enforcing its restraints, a key is inserted and then turned to the bypass position. The manual indicator light will illuminate and all error and alarm displays will go blank.

Out of Sequence-System Initialize Pushbutton Switch/Indicator

The system initialize switch is used to initialize the RWM program. Initialization is performed whenever the RWM has been removed from service, either by manual bypass or if the program is aborted. The system initialize portion of the window illuminates while the switch is held down. The amber OUT of SEQ light is energized under the program control whenever the LPAP is reached and a withdraw error exists or greater than two insert errors exist.

The purpose of the light is to warn the operator that there is incompatibility between the latched sequence and the existing rod position information. In addition it also informs the operator that a failure to correct the problem will result in an insert block when the LPSP is reached.

Rod Test-Select Pushbutton Switch/Indicator

The rod test switch is used to place the RWM program in the rod test mode. To enable the switch, all control rods must be fully inserted. If this condition exists, the select indicator illuminates white when the rod test switch is depressed. While in the rod test mode any one control rod may be selected and moved to any position, provided that all remaining control rods are fully inserted. The rod test mode can be terminated by depressing the rod test switch again. The rod test mode is used during refueling when a single rod is moved to verify friction is at a minimum following fuel loading of that control cell.

System Diagnostic Switch/Indicator

The diagnostic switch can be depressed at any time after the system has been initialized to request the RWM program to run a diagnostic routine. When the routine is accepted by the RWM program it will start applying and removing insert and withdraw blocks. While in the diagnostic mode, the operator verifies the operability of the rod block circuits by observing the insert and withdraw block alarm lights are received and extinguished in concert with the RWM.

The diagnostic routine continues until the switch is depressed again. Once the diagnostic routine has been terminated the RWM must be re-initialized with the system initialize pushbutton.

RWM - COMP - PROG Pushbutton Switch/Indicator

The three segments of this indicator are used to alarm various hardware and software failures within the RWM. This switch is used to verify the indicator lights are operative and to reset the lamp drive circuits for these indicators in the output buffer. The PROG section of the indicator is lit whenever the RWM program is inoperative (not initialized, manually bypassed, or program has aborted). COMP illuminates whenever a computer stall or bit parity check error occurs. The RWM section lights when ever a COMP or PROG is in alarm state. When the pushbutton is depressed, all three of the indicators will back light, until it is released. If the alarm condition has cleared the light(s) will extinguish.

7.5.3 System Features and Interfaces

A short discussion of system features and interrelations between this system and other plant systems is given in the paragraphs that follow.

7.5.3.1 Rod Drop Accident

During low power and startup operation, unrestrained rod patterns can create rods of sufficient worth to exceed design limits in a Rod Drop Accident. The results of a design bases rod drop accident is a rapid, very high power spike in the fuel, causing fuel temperature to increase. The increase in fuel temperature will turn reactor power initially (doppler coefficient), followed by a reactor scram on high flux initiated by the Intermediate Range and/or Average Power Range Monitoring System. The time duration of the power spike is very short compared to the fuel time constant, so all generated energy is deposited in the fuel pellets. As fuel enthalpy increases, the fuel melts, vaporizes, and begins to pressurize the fuel rods. Table 7.5-1 lists results of experiments and analysis of fuel behavior for various fuel enthalpies. A value of 280 calories per gram is considered for the design limit for a rod drop accident. Beyond a value of 280 calories a rapid fuel rod failure is expected.

Table 7.5-2 lists the sequence of events of a rod drop accident to occur. Note that each of the required events has a small probability of occurrence, therefore, the accident itself has a very low probability. The possible consequences of such an accident however, requires that some means be provided to reduce this probability.
Given that the sequence of events can occur, its consequences depends upon initial reactor power level, control rod reactivity worth, moderator

temperature, core age, the distance the control blade drops, and the rate of control rod blade free fall. Fuel damage will probably occur as a result of the worst case rod drop accident.

Rod movement sequences are developed to limit rod worth to a value below which, if a rod drop accident were to occur at a rate limited by the velocity limiter, the fuel enthalpy from the transient would be less than 280 cal/gm. Rods are withdrawn in a symmetrical fashion to distribute power generation as evenly as possible throughout the core.

Below 20% power, selecting and withdrawing an in sequence control rod is permitted. If the highest worth, in sequence, control rod blade were to fall from the full in to the full out position, less than 280 cal/gm heat generation will result. As power is increased above 20%, increased voiding occurs in the core. This increased voiding flattens the flux profile surrounding a control rod. Should a control rod drop occur at this power level, the reactivity change will be much less pronounced than that at power levels below 20%.

The effect of a rod drop at high power would be distributed over a larger core region, resulting in lower local heat generation. Therefore, the RWM does not enforce rod patterns above 20% power. A correct sequence rod drop will result in a fuel enthalpy less than 100 cal/gm.

At higher power levels, the fuel rod linear heat generation rate (LHGR) is closer to the LHGR limit. Therefore, even with a less pronounced control rod reactivity effect due to voiding in the core, it is possible to exceed the LHGR limit.

7.5.3.2 Normal Operation

Prior to withdrawing any control rods, the operator must ensure the RWM program is loaded and the correct rod withdraw sequence is selected. The operator ensures the Normal-Bypass switch in the normal position and depresses the system initialize pushbutton.

When initialized, the rod group window on the operator's panel will display 01. This indicates that rod group 1 is latched. By following the rod withdraw procedure the operator will withdraw all of the group 1 rods to the full out position (48). NOTE: The RWM sequence restraints do not specify the order of rod withdraw. When the last rod in group 1 is moved to its withdraw limit, the rod group indication will automatically update to 02. As each rod group moved to its withdraw limit and a rod from the next higher group is selected, the rod group window will update. Similar, when inserting rods, the window will shift down in the same manner. Several items should be emphasized in the forgoing example:

1. When withdrawing or inserting control rods it is completely acceptable to the RWM program to leave the rod(s) at the alternate limit.
2. When withdrawing, any two rods could be left at their insert limits. The two rods would be displayed as insert errors on selection of the next higher group. Only two such errors are allowed.
3. If a rod is selected that is not in the currently latched group a select error will be indicated. This will not restrain movement of that rod, but indicates that if it is moved an insert or withdraw error will result and possible rod block.

7.5.3.3 Latching Operation

The purpose of latching is to update the RWM monitoring and determine the correct latched group. In the latching operation the RWM scans control rod positions to determine the highest numbered group (i) such that:

1. In all groups 1 through i-1 there are less than three insert errors.

2. Group i has at least one rod withdrawn past its insert limit.

The latching operation takes place whenever:

1. System initialize pushbutton is depressed.
2. Any error is corrected.
3. Every 5 seconds in the transition zone.
4. Power drops below the LPAP or LPSP.
5. Operator demands termination of rod test.

7.5.3.4 Operation With Errors

Operation is allowed with up to two insert errors without restraints, a third will result in an insert rod block requiring the correction of at least one of the errors. Once a withdraw error is made, a withdraw block is applied and must be corrected.

7.5.3.5 System Interfaces

A short discussion of interrelations between this system and other plant systems is given in the paragraphs that follow.

Reactor Manual Control System

The reactor manual control system provides rod selected data and receives rod block signals.

Control Rod Drive System

The CRD system provides control rod position information to the RWM.

Main Steam System

The main steam system provides signals to the RWM that are used for the LPSP and LPAP functions.

Process Computer

The process computer is the central component of the RWM.

7.5.4 Summary

Classification - Safety related system

Purpose - Serve as a backup to procedural controls and to limit rod worth during low power operation.

Components - Process computer, RWM program, RWM operators panel, system interrelations - Process computer, Reactor Manual Control System, Control Rod Drive System, Main Steam System.

Table 7.5-1 Fuel Behavior for Various Fuel Enthalpies

Fuel Enthalpy	**Result**
170 calories/gram	Threshold for cladding perforation
200-280 calories/gram	Fuel melting
425 calories/gram	Fuel melting complete; UO_2 vapor pressure rise of 30 psi/second. (This enthalpy is the design limit)
450 calories/gram	UO_2 vapor pressure rise of 600 psi/second

Table 7.5-2 Events Required for a Rod Drop Accident to Occur

- Failure of control rod blade to drive mechanism coupling.
- Control rod blade sticks in core.
- The drive mechanism is fully withdrawn from the core.
- Failure of the control room operator to observe lack of neutron monitoring response when the control rod is withdrawn.
- Failure of the operator to verify coupling between the blade and drive mechanism.
- Control rod blade becomes unstuck and falls from the core area.

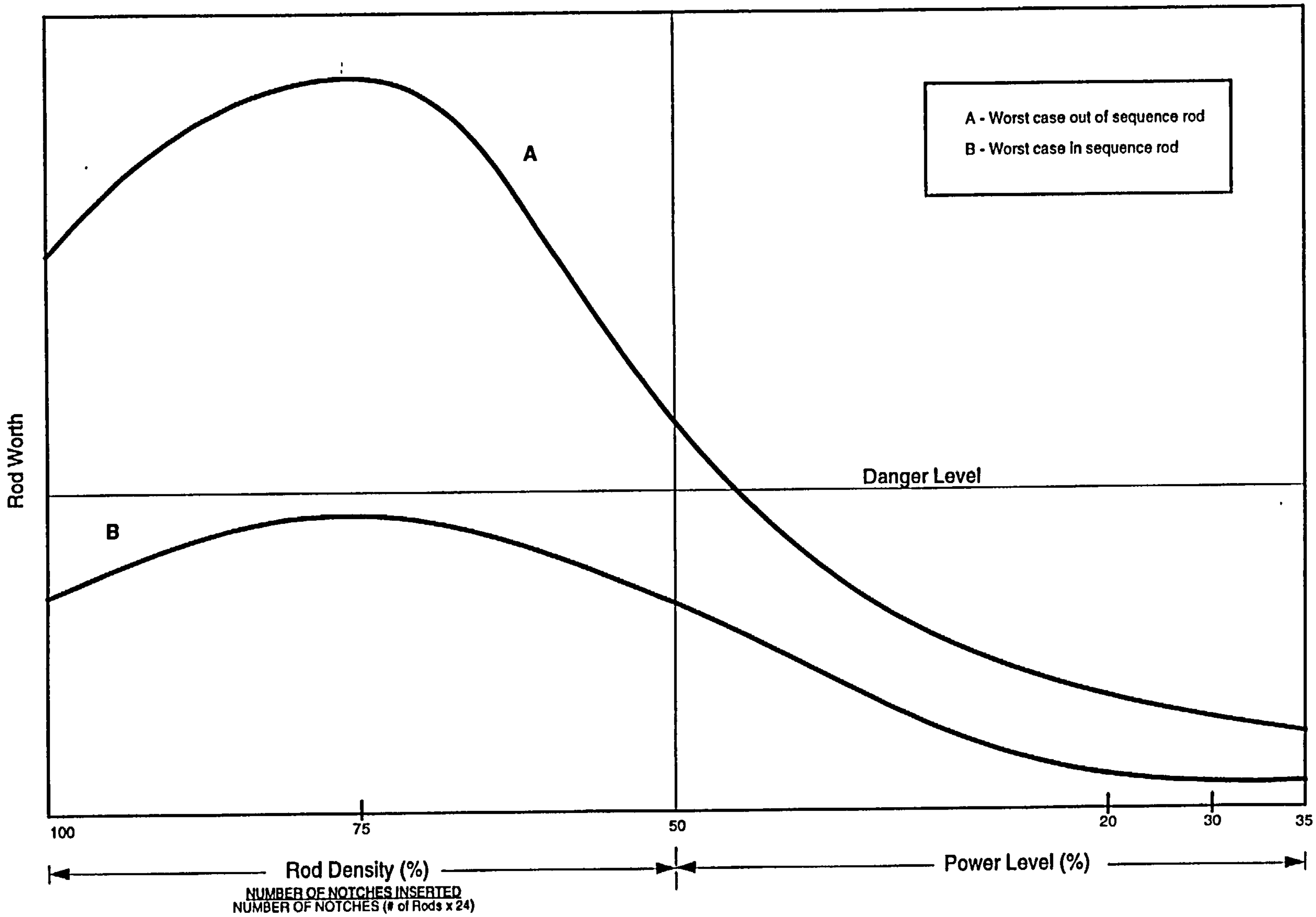

Figure 7.5-1 Rod Worth for Sequences of Rod Withdrawal or Insertion

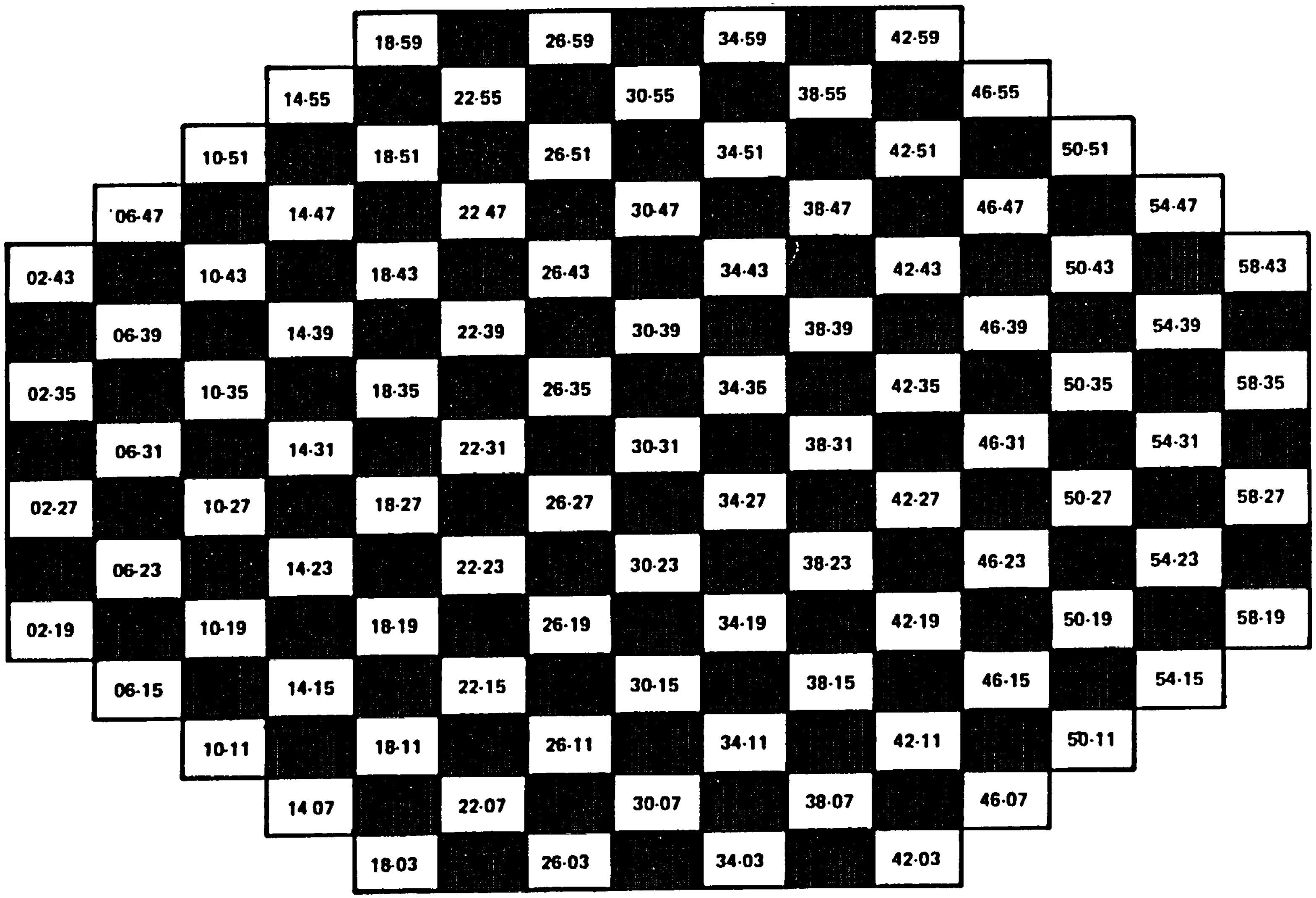

FIGURE 7.5–2 BLACK AND WHITE PATTERN FOR "A" SEQUENCE

RWM Group #	Rods in the Group
1	26-31, 34-39, 42-31, 34-23, 26-15, 18-23, 10-31, 18-39, 26-47, 42-47, 50-39, 50-23, 42-15, 34-07, 18-07, 10-15, 02-23, 02-39, 10-47, 18-55, 34-55, 58-31
2	34-31, 26-23, 18-31, 26-39, 34-47, 42-39, 50-31, 42-23, 34-15, 18-15, 10-23, 10-39, 18-47, 26-55, 42-55, 50-47, 58-39, 58-23, 50-15, 42-07, 26-07, 02-31
3	30-35, 38-27, 30-19, 22-27, 14-35, 22-43, 30-51, 38-43, 46-35, 54-27, 46-19, 38-11, 22-11, 14-19, 06-27, 06-43, 14-51, 22-59, 38-59, 46-51, 54-43, 30-03
4	30-27, 22-35, 30-43, 38-35, 46-27, 38-19, 30-11, 22-19, 14-27, 14-43, 22-51, 38-51, 46-43, 54-35, 54-19, 46-11, 38-03, 22-03, 14-11, 06-19, 06-35, 30-59
5	58-43, 42-03, 02-19, 18-59, 58-19, 18-03, 02-43, 42-59
6	50-11, 10-11, 10-51, 50-51
7	42-19, 18-19, 18-43, 42-43
8	34-27, 26-27, 26-35, 34-35
9	34-03, 02-27, 26-59, 58-35, 26-03, 02-35, 34-59, 58-27
10	14-07, 06-47, 46-55, 54-15, 06-15, 14-55, 54-47, 46-07
11	18-27, 26-43, 42-35, 34-19, 18-35, 34-43, 42-27, 26-19
12, 13, 15, 19, 21, 28, 31, 35, 40	18-11, 10-43, 42-51, 50-19, 42-11, 10-19, 18-51, 50-43
14, 16, 20, 22, 26, 29, 32, 36, 41, 47	26-11, 10-35, 34-51, 50-27, 34-11, 10-27, 26-51, 50-35
17, 23, 27, 30, 33, 38, 45, 49, 52	22-47, 46-39, 38-15, 14-23, 22-15, 14-39, 38-47, 46-23
18, 24, 34, 39, 46, 50, 53	30-23, 22-31, 30-39, 38-31
37, 42, 54, 58, 65	30-07, 06-31, 30-55, 54-31
43, 48, 55, 62, 70	14-15, 14-47, 46-47, 46-15
44, 56, 61	30-31, 22-39, 38-39, 38-23, 22-23
51, 59, 63	22-07, 06-39, 38-55, 54-23, 38-07, 06-23, 22-55, 54-39
57, 60, 69	14-31, 30-15, 46-31, 30-47
64, 72	38-07, 06-23, 22-55, 54-39
66	22-47, 46-39, 38-15, 14-23
67	22-15, 14-39, 38-47, 46-23
68	30-23, 22-31, 30-39, 38-31
71	22-07, 06-39, 38-55, 54-23

FIGURE 7.5-3 TYPICAL RWM GROUPS (FOR SEQUENCE A)

RWM Group	Withdraw Position	Check	RWM Group	Withdraw Position	Check
1	00-48		37	00-04	
2	00-48		38	20-24	
3	00-48		39	14-18	
4	00-48		40	42-48	
5	00-48		41	36-42	
6	00-48		42	04-08	
7	00-48		43	00-04	
8	00-48		44	00-04	
9	00-48		45	24-28	
10	00-48		46	18-22	
11	00-48		47	42-48	
12	00-04		48	04-08	
13	04-08		49	28-32	
14	00-04		50	22-26	
15	08-12		51	00-04	
16	04-08		52	32-36	
17	00-04		53	26-30	
18	00-04		54	08-12	
19	12-16		55	08-12	
20	08-12		56	04-08	
21	16-20		57	00-04	
22	12-16		58	12-16	
23	04-08		59	04-08	
24	04-08		60	04-08	
25	20-24		61	08-12	
26	16-20		62	12-16	
27	08-12		63	08-12	
28	24-30		64	08-12	
29	20-24		65	16-12	
30	12-16		66	36-42	
31	30-36		67	36-42	
32	24-30		68	30-36	
33	16-20		69	08-12	
34	08-14		70	16-20	
35	36-42		71	12-16	
36	30-36		72	12-16	

FIGURE 7.5-4 TYPICAL CONTROL ROD WITHDRAWAL SEQUENCE (SEQUENCE A)

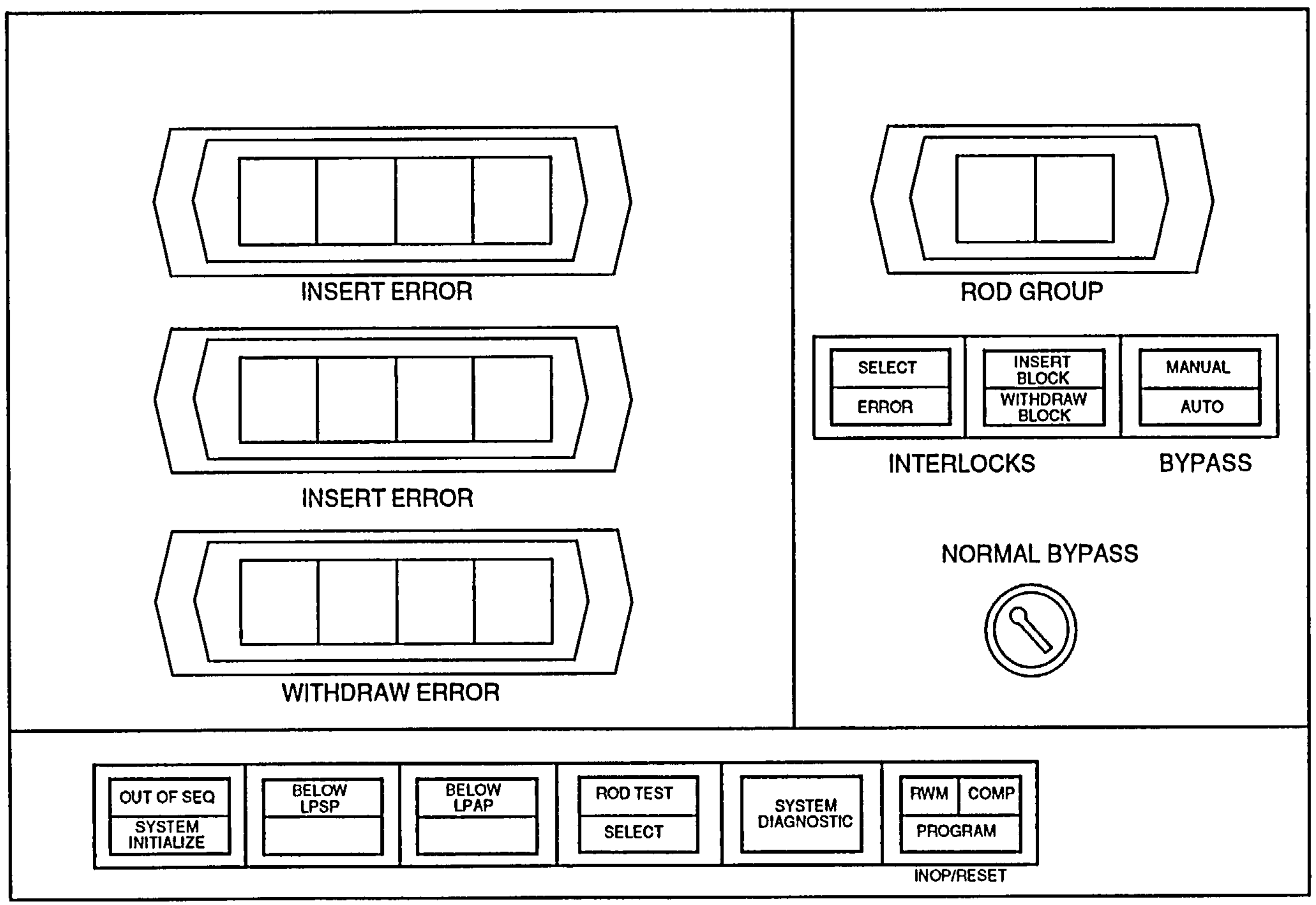

Figure 7.5-5 RWM Operator's Display Panel

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Chapter 8.0

Radioactive Waste Processing and Monitoring Systems

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8.0 RADIOACTIVE WASTE AND MONITORING SYSTEMS

8.0.1 Introduction

The Radioactive Waste and Monitoring Systems are monitoring and support systems designed to monitor, collect, process, store, and prepare for off site shipment and disposal, plant wastes which contain or could contain radioactive material. The radwaste systems consist of the following:

1. Offgas System (Gaseous Radwaste) (Section 8.1)
2. Liquid Radwaste System (Section 8.2)
3. Solid Radwaste System (Section 8.3)
4. Process Radiation Monitoring System(Section 8.4)
5. Area Radiation Monitoring System (Section 8.5)
6. Post Accident Sampling System (Section 8.6)

8.0.2 Offgas System

The Offgas (OG) System functions to reduce the off site exposures at the nearest site boundary to less than the established maximum limit. The Offgas System performs its function by reducing the offgas volume, by recombining radiolytic hydrogen and oxygen into water, and delaying passage of krypton and xenon, by adsorption on charcoal, to permit decay.

8.0.3 Liquid Radwaste System

The liquid waste disposal is a batch controlled process. Water and other process solutions are collected in tanks, processed, and again collected as batches in tanks. The tanks are analyzed for radioactive material and chemical content to determine both the method of processing and reusability as condensate or disposal off site by dilution in an effluent canal. Processing consists of filtration, demineralization, distillation, concentration, and decay.

8.0.4 Solid Radwaste System

The Solid Radwaste System is used to process wet and dry solid waste for shipment from the facility. Wet wastes are dewatered and packaged in 55 gallon drums. Dry wastes are compacted to reduce free volume and packaged in approved shipping containers or 55 gallon drums as required.

8.0.5 Radiation Monitoring System

The Area Radiation Monitoring System monitors the gamma radiation level of selected working and storage areas within the plant buildings.

The Process Radiation Monitoring System monitors the radiation levels of various process liquid and gaseous flows that may serve as discharge routes for radioactive materials.

8.0.6 Post Accident Sampling System

The Post Accident Sampling System allows for sampling of reactor water, RHR water, and containment gases for radioisoptic analysis during and following accident conditions within reasonable exposure limits.

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Chapter 8.1

Offgas System

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8.1 OFF GAS SYSTEM

Learning Objectives:

1. State the system's purpose.
2. Explain how the system accomplishes its purpose.
3. Describe the sources of noncondensible gases.
4. Place major system components in flow path order and explain the purpose of each.
   a. CAR Pumps
   b. SJAE and coolers
   c. Booster SJAE's
   d. Preheater
   c. Recombiner
   d. Desuperheater condenser and drain cooler
   e. Cooler condenser
   f. Sacrificial decay beds
   g. Cyclic dryer units
   h. Charcoal adsorber tanks
   i. After filters
   j. Discharge isolation valve
   k. Station ventilation booster fans
5. Explain how this system interfaces with the following systems or components:
   a. Main Condenser
   b. Main Steam System
   c. Condensate and Feedwater System

8.1.1 Introduction

The purpose of the Off Gas system is:

1. To establish and maintain a vacuum in the main condenser to improve turbine efficiency by removing non condensible gases from the main condenser
2. To process non condensible gases in order to limit the release of radioactive gases to as low as is reasonably achievable(ALARA).

The Offgas System processes and controls the release of gaseous radioactive effluents from the condenser to the site environs so that the total radiation exposure to persons outside the controlled area do not exceed the limits of 10 CFR 20 and the dose objectives of 10 CFR 50 Appendix I, as low as reasonably achievable.

The Offgas System is functionally classified as a power generation system.

8.1.2 System Description

During power operation steam spins the main turbine and exhausts into the condenser where the majority of it is condensed by the circulating water system. Air entering the system and other non condensible gases formed during operation also end up in the condenser. These non condensibles would cause an increase in condenser pressure or loss of vacuum which would reduce the amount of work produced by the turbine and eventually cause a turbine trip on low vacuum.

The non condensibles are removed from the condenser by condenser air removal pumps (CAR's) and/or steam jet air ejectors (SJAE's). The CAR pumps are also called mechanical vacuum pumps. The CAR pumps are used to initially evacuate the condenser down to at least 20" mercury vacuum before the SJAE's are placed into service. The SJAE's then evacuate the condenser down to approximately 28 to 30 inches. The CAR's can only pull approximately 25" vacuum and will trip off at 25".

The CAR's are motor driven and the SJAE's are steam driven. The steam can be supplied from either the auxiliary boiler or the main steam system thus condenser vacuum can be establishedbefore the reactor is taken critical and/or the production of steam by the nuclear boiler. SJAE's operate by the same principle as the reactor recirculation jet pumps (Figure 8.1-2).

Before condenser vacuum is established the main turbine is placed on turning gear then seal steam is established. Next the CAR's (one or both) are placed in service and the condenser vacuum breakers are closed and sealed with water. Air is removed from the condenser and discharged to the turbine building ventilation system. The CAR's are used only for initial evacuation for two reasons, 1)because they can only pull 25" of vacuum(turbine efficiency) and 2) because their discharge is not processed they are not allowed to be used when greater than 4% of rated power.
The non condensible gases are primarily comprised of air, fission product gases ,water activation gases and radiolytic gases, assuming no fuel failure. These gases are drawn into the SJAE's as well as some steam vapor. As all of these make up the total volume of flow each then makes up a % by volume of the total. The fission product gases primarily consist of the noble gases xenon and krypton and a halogen, iodine. The water activation products consist of isotopes of nitrogen, oxygen, hydrogen and fluorine. Table 8.1-1 provides a list and shows the formation mechanism and half lives of these products. The components used in the processing of the off gas are designed to increase the hold up time in the system to allow for radioactive decay or to filter out the radioactive products.

The offgas system contains the following major components (Figure 8.1-4):

a. CAR Pumps
b. SJAE and coolers
c. Booster SJAE's
d. Preheater
e. Recombiner
f. Desuperheater condenser and drain cooler
g. Cooler condenser
h. Sacrificial decay beds
i. Cyclic dryer units
j. Charcoal adsorber tanks
k. After filters
l. Discharge isolation valve
m. Station ventilation booster fans.

The components which increase the holdup time are the recombiner/condenser and charcoal.The majority of the rest of the equipment is to support and/or increase the efficiency of these components. As stated previously the CAR pumps are used to initially evacuate the condenser and do not process radioactive materials. The station ventilation booster fans are used to dilute the off gas after processing and provide the motive force for dispersal into the atmosphere. The discharge isolation valve is used to terminate off gas flow in the event the system does not satisfactorily reduce the radioactive materials to within the prescribed limits.

Air enters the off gas system from various places; fittings in the condensate system, pump shafts,tube leaks, SJAE fittings, boot seals, etc... The air is not processed out and in fact after the remaining gases are processed out it plays an important role as a dilutant and as a carrier gas.

The radiolytic gases are produced as a result of the disassociation of water by a neutron flux forming free hydrogen and oxygen. The hydrogen presents a separate problem in that above 4% by volume it may explode in the presence of oxygen. The recombiner is used to combine the hydrogen and oxygen into water vapor thus removing this threat. Thus the recombiner in conjunction with it's desuperheater condenser performs two functions:

1. Recombine H_2 and O_2 to preclude an explosion in the system, losing system integrity.

2. In combining H_2 and O_2 into water vapor and then cooling and condensing and removing the water it reduces the flow rate in the system which increases holdup time in the system , specifically in the charcoal.

The first stage of the SJAE's removes the non condensibles and some steam vapor from the condenser and mixes with the driving steam. This mixture then enters the SJAE intercooler where condensate from the condensate and feedwater system cools the stream condensing the steam to reduce wear in the second stage nozzle. The condensed steam (condensate) drains from the cooler to the main condenser through a loop seal. The off gas goes on to the second stage SJAE where the driving steam and off gas mix again and continue on to the offgas inlet booster ejector. The booster ejector provides the motive force to move the gas through the remaining portion of the system, dilutes the gases to where the % by volume of H^2 is less than 4%, and aids in preheating the gas prior to entering the recombiner.

The recombiner has a material in it (platinum palladium) which causes the H^2 and O^2 to combine at a lower temperature than would otherwise be required. However, the gas stream must still be heated to some minimum temperature, typically greater than 350°F, in order to commence the reaction. In addition the steam must be heated sufficiently to minimize any moisture going into the recombiner as this reduces the efficiency of the recombiner. The preheater performs this function. The source of heat for the preheater is the main steam system or the auxiliary boiler. The reaction in the recombiner is an exothermic reaction thus the temperature out of the recombiner is variable depending on the % by volume of H^2 being reacted. If 4% by volume of H^2 is being combined the outlet temperature is approximately 850°F. If you change the amount of driving steam into the booster ejector you will change the % by volume of H^2 and thus effect the temperature out of the recombiner. In effect this driving steam acts as a coolant for the recombiner.

Since the reaction adds heat to the gas it is superheated when it leaves the recombiner and enters the desuperheater condenser where it is cooled by the turbine building closed loop cooling water system (TBCLCW) to 150°F causing more condensation. The condensate is further cooled in the drain cooler and sent to the low conductivity drain sump. From this sump it can be routed to either the main condenser or to radwaste. The remaining gas continues on to the cooler condenser where the gas is further cooled to a 40°F dew point by a glycol refrigerant system thus removing more water from the system. The condensate from the cooler/condenser drains to the drain cooler where it is also sent to the low conductivity drain sump. The remaining components of the gas (air, water activation products and fission products) continue on for further processing. The sacrificial bed contains charcoal which provides the first long term hold up of radioactive gases. The shorter lived gases decay into particulate daughter products and remain in the bed to prevent fouling of downstream equipment.

The gas continues on to the dryers where more moisture is removed reducing the dew point to 0°F prior to entering the charcoal adsorber tanks. The efficiency of charcoal (the time gases adhere to it) is a function of moisture in the gas, temperature of the gas and charcoal and flowrate(CFM) in the system. In the charcoal tanks the gas has an affinity for adhering to the charcoal depending on the gas type. Iodine is also trapped in the earlier tanks and the xenons and kryptons are adhered for days and hours respectfully.

The remaining gases continue on to HEPA after filters where any charcoal fines/dust and particulates are retained.

Then on through the off gas isolation valve to the station ventilation exhaust booster fans and out to the elevated release point.

Continuous radiation monitoring provides indications of radioactivity into and from the Offgas System. Sampling points are prior to the booster steam jets and the offgas isolation valve. These monitoring systems alarm when levels reach their setpoints with no automatic trip functions.

8.1.3 Component Description

The condenser air removal equipment consists of two CAR pumps and two sets of SJAE's. Two gaseous radwaste trains are provided to process the main condenser off gas stream from the SJAE prior to atmospheric release. One train is normally in service while the other is in standby. Each train is comprised of the following redundant sections; the recombiner section, the sacrificial decay bed section and the dryer section.
Down stream of the dryer section is a common charcoal adsorber section and an after filter section.

The major components of the Condenser Air Removal and Offgas System are discussed in the paragraphs that follow.

8.1.3.1 Condenser Air Removal Pumps

There are two CAR pumps, A and B, each having 100% capability. The CAR pumps are used to remove air and noncondensibles from the main condenser during startup. Four motor operated 12" gate valves connect the two CAR pumps to the two main condensers through four more motor operated 12" gate valves which isolate the condensers from the system. Each pump has an air operated 12" suction butterfly valve which fails closed on loss of air. The pumps are axial flow compressors with a shaft driven oil pump, cooled by TBCLCW and operated from the main control room. The pumps trip at 25"vacuum. A radiation monitor on the common piping gives indication and annunciation of high radiation conditions.

Inlet separator tanks remove water from the inlet to the pumps and a discharge silencer drain tank reduces noise and removes water from the pump discharge. A seal water injector unit provides water to seal the pumps and to control the discharge temperature.

8.1.3.2 Steam Jet Air Ejectors

There are two sets of steam jet air ejectors, A and B. Each set consists of two stages, first and second. The first stage has two jets in parallel followed by a condenser (intercondenser) and the second stage has one jet. Each set of SJAE's is rated for 100% capacity. Each SJAE uses a high velocity jet of steam to create a low pressure for the removal of noncondensible gases from the main condenser shells. The nozzle accelerates the steam to such a high velocity that it passes through the diffuser throat as it begins to expand. Gas molecules present in the suction chamber become entrained in the steam and are carried by the steam.

Either the main steam system or the auxiliary boiler can supply the steam. Main steam, reduced to 115 psig, is supplied through a strainer to each SJAE nozzle. A second PCV set at 110 psig is used as a backup. Operation of these valves is erratic until reactor pressure reaches 300 to 350 pounds.

The two first stage jets in each SJAE set discharge directly into the shell of an intercondenser. This steam is condensed by condensate flowing through tubes in the intercondenser. This process also provides some preheating of the feedwater. The condensate is allowed to drain back to the main condenser shell through a loop seal which prevents noncondensible gases from returning to the condenser.The intercondenser normally operates at about 20 inches Hg.

The second stage jet takes suction from the intercondenser and discharges to the remainder of the offgas system at a pressure of about 3 pounds. The second stage air ejectors are noncondensing. This allows the driving steam to dilute the radiolytic hydrogen, which is a significant portion of the noncondensible gases, in order to maintain the hydrogen concentration to less than 4% by volume. The outlet of the SJAE has a radiation monitor which indicates in the control room with one of it's alarm points set to meet the Technical Specification release limit.
An air purge supply with a capacity equal to the minimum design condenser air inleakage flow is provided upstream of the recombiner. When the condenser air inleakage falls below the design minimum of 6 scfm and the hydrogen concentration exceeds 1%, the air purge is initiated to provide sufficient hydrogen dilution.

8.1.3.3 Booster Ejector's

There are two types of booster ejectors, the offgas inlet booster ejector and the dryer regeneration booster ejector. The offgas inlet booster ejector provides the motive force to move the off gas through the remaining portion of the system, dilutes the hydrogen and adds heat to the gas stream. The dryer regeneration booster ejector provides the motive force to remove moisture from the dryer being regenerated and discharges into the suction of the offgas inlet booster ejector. The driving steam for both boosters is supplied from either the main steam system or the auxiliary boiler.

The driving steam for the offgas inlet booster ejector mixes with the gases from the SJAE's and the dryer regeneration booster ejector to ensure the hydrogen concentration is less than 4% by volume. The 4% hydrogen monitor is located on the discharge of the booster. The driving steam adds heat to the gas stream which aids in the preheating of the gas to support recombiner operation.The booster ejectors are located in the turbine building , one each per recombiner skid.

8.1.3.4 Preheater

The preheater maintains the off gas stream recombiner inlet temperature greater than 382°F. This temperature is required to support the recombination of H_2 and O_2 and to prevent wetting of the catalyst as moisture reduces the efficiency of the recombiner.
Steam from the main steam system is the normal source of heat; however, steam from the auxiliary boiler may be used. The steam flows through the heat exchanger tubes and as it gives up heat condenses to water and is piped back to the main condenser. The offgas stream flows through the shell side of the exchanger.

The outlet temperature of the heater is maintained at the desired setting by using a temperature sensor to control a TCV in the steam supply.The preheaters are located on the recombiner skids.

8.1.3.5 Catalytic Recombiner

The catalytic recombiner contains a platinum palladium catalyst which promotes the recombination of radiolytic hydrogen and oxygen contained in the Offgas System. The amount of hydrogen and oxygen in the process stream resulting from radiolytic decomposition varies directly with reactor power. Approximately 0.03 to 0.055 scfm of hydrogen and oxygen are produced for each thermal megawatt of reactor power.

Offgas enters the recombiner at 382°F and exits at 850°F. The purpose of the recombiner is to reduce the hydrogen concentration below the explosive limit of 4% and to reduce the flow rate (CFM) in the system to increase the efficiency of the charcoal.. During normal operation, the process stream leaving the catalyst contains less than 0.1% H_2 by volume. Maximum permissible H_2 levels under any condition are not to exceed 1.0% H_2 by volume. A 1% moisture analyzer is located after the cooler condenser.

Externally mounted heaters are used to maintain the standby recombiner temperature greater than 350°F.

8.1.3.6 Desuperheater Condenser and Drain Cooler

The desuperheater condenser is designed to reduce the offgas temperature from 850°F to less than 150°F. The superheated steam leaving the catalyst is subcooled by a desuperheater condenser which is a shell and tube heat exchanger with the off gas stream on the shell side and TBCLCW on the tube side. This condenser in conjunction with the cooler condenser cools and removes moisture from the superheated process stream. An integral separator removes any entrained moisture. The condensate and separated moisture are collected in a drain cooler which is also cooled by TBCLCW. The drain cooler drains to the low conductivity drain tank which can be routed to either the main condenser or liquid radwaste.

The desuperheater condenser is located on the recombiner skid.

8.1.3.7 Cooler Condenser

The cooler condenser provides a second stage of moisture removal from the process stream lowering it's dewpoint to 40°F. The condenser is a shell and tube heat exchanger with the offgas on the shell side and a chilled(35°F) glycol solution on the tube side.

An integral moisture separator removes moisture from the stream and along with the condensate is routed to the low conductivity drain tank. A 1% hydrogen analyzer is installed after the cooler.

The cooler condenser is located on the recombiner skid.

8.1.3.8 Sacrificial Decay Beds

There are two 100% capacity decay beds. Each bed contains 1,135# of charcoal. One bed is normally in operation with the other in standby. The beds provide the first stage of adsorptive delay for the decay of radioactive gases. The short lived isotopes of xenon and krypton decay into particulate daughter products and are retained in the bed. The sacrificial beds minimize the contamination of downstream components and extend the life of the charcoal in the charcoal adsorber tanks. The sacrificial decay beds are located in the radwaste building.

8.1.3.9 Cyclic Dryer Units

The cyclic dryers provide the final stage of moisture removal from the off gas stream lowering it's dewpoint to 0°F. The lower the moisture level is in the process stream leaving this adsorber the more efficient the charcoal adsorbers.

There are two 100% capacity desiccant dryer units. One dryer is in service and one in regeneration. Each bed is in service for 24 hours. Six pneumatically operated valves control this sequence. A small portion of the total flow is routed through an electric heater(3.5 KW) which heats the stream to 500°F. The heater is energized for 16 hours removing the moisture from the desiccant and returning it to the regeneration booster ejector.

After 16 hours the heater is de-energized for 8 hours to allow the unit to cool then units are swapped.A moisture analyzer is located after the dryer units.

The dryer units are located in the radwaste building.

8.1.3.10 Charcoal Adsorber Tanks

The charcoal adsorber tanks provide the final stage of adsorptive delay for the decay of radioactive gases. As the offgas flow passes through the charcoal bed, the air, which is present from air inleakage, acts as a carrier gas for the xenon and other fission product gases. The short term isotopes of xenon and krypton are delayed sufficiently to allow them to decay into their particulate daughter products. These solid particulates are retained in the bed. Radioactive decay produces some heat(decay heat) in the beds. The higher the temperature of the gas or the charcoal the shorter the holdup time. The higher the flow rate(CFM) in the system the shorter the holdup time. The dynamic adsorption coefficient for xenon is much greater than that for krypton thus xenon has a holdup time in the order of days versus hours for krypton.

There are ten charcoal adsorber tanks arranged in two parallel trains of five tanks. The flow path can be arranged to pass through both trains in parallel or place the two trains in series. The first tank in each train may also be bypassed. The flow path is controlled by air operated valves from the off gas control panel. Radioiodine input into the offgas system is small by virtue of its retention in the reactor water and condensate. The iodine remaining is essentially removed by adsorption in the charcoal. The adsorber tanks are located in the radwaste building.

8.1.3.11 After Filters

The after filters are installed downstream of the charcoal adsorber beds to prevent the release of carbon dust into the plant ventilation system. The after filters are high efficiency particulate (HEPA) filters designed to remove 99.97% of all particles 0.3 micron and larger.

There are two 100% capacity filters. Normally one filter is in service and the other in standby. A radiation monitor is located after the filters to determine system efficiency and release rates with alarms based on Technical Specification limits.The filters are located in the radwaste building.

8.1.3.12 Station Ventilation Booster Fans

The station ventilation booster exhaust fans in the turbine building ventilation system dilute the off gas prior to discharge. The station vent discharges the off gas from an elevated stack which disperses the gas over a wider area.

8.1.4 System Features

A discussion of system features and interrelations between this system and other plant systems is discussed in the paragraphs that follow.

8.1.4.1 System Operation

During startup, initial condenser vacuum is established using the CAR pumps(one or both). Warmup of the off gas preheater and recombiner should be initiated as needed to support startup and eventual shift from the air removal pumps to the air ejectors. If nuclear steam is at a low pressure or not available the auxiliary boiler can be used to operate the SJAE's and preheaters. The charcoal adsorber tanks are initially bypassed. When condenser vacuum exceeds 20" Hg one or both SJAE's are placed in service. When condenser vacuum reaches 24" Hg both CAR pumps are stopped and their suction valves are closed. When condenser vacuum reaches 27" Hg , one SJAE is shutdown and flow is established through the charcoal adsorber tanks. When reactor pressure is high enough(300-350#) the supply steam to the SJAEs is shifted to the main steam system..

8.1.5 System Interfaces

The interfaces between this system and other plant systems are discussed in the paragraphs that follow.

Main Steam System (Section 2.5)

The Main Steam System is the normal supply of reduced pressure steam to the steam jet air ejectors, booster ejectors and preheaters.

Auxiliary Steam System

The auxiliary steam system supplies steam to operate the SJAE's, booster ejectors and preheaters if main steam is not available.

Service and Instrument Air System (Section 11.8)

The Service and Instrument Air System supplies the offgas system with air to operate pneumatic valves and air to purge the offgas system.

4160 V Normal Distribution System (Section 9.1)

The Normal Distribution System supplies electrical power to the refrigeration units, recombiner standby heaters,Cyclic heaters, CAR pumps, and other miscellaneous loads.

Condensate and Feedwater System (Section 2.6)

The Condensate and Feedwater System supplies cooling water to SJAE intercondenser.

Turbine Building Closed Loop Cooling Water System

The TBCLCW system supplies cooling water for the desuperheater condenser and drain cooler.

Process Radiation Monitoring System (Section 8.4)

The Process Radiation Monitoring (PRM) System monitors the radioactivity levels at the discharge of the CAR pumps, the SJAE's and the After filters providing alarms at predetermined levels.

8.1.6 Summary

Classification - Power generation system

Purpose - To process and control the release of gaseous radioactive effluents from the condenser to the site environs so that the total radiation exposure to personnel outside the controlled area does not exceed the limits of 10 CFR 20 and as low as reasonably achievable (ALARA) criteria.

Components - CAR pumps, SJAE's and coolers, Booster SJAE's, preheater, recombiner, desuperheater condenser and drain cooler, cooler condenser, sacrificial decay beds, cyclic dryer units, charcoal adsorber tanks, after filters, a discharge isolation valve and the station ventilation booster fans.

System Interrelations - Main Steam System, Auxiliary Steam System Service and Instrument Air System, 4160 V Normal Distribution System, Condensate and Feedwater System, Process Radiation Monitor System

TABLE 8.1-1 PRINCIPAL ISOTOPES IN THE OFFGAS FLOW

Activation Products Of Water

Nuclide	Half-life	Formation Mechanism
N-16	7.1 seconds	O-16(n,p)N-16
O-19	29 seconds	O-18(n)O-19
N-13	10 minutes	O-16(p,a)N-13
F-18	110 minutes	O-18(p,n)F-18
H-3 (tritium)	12.33 years	H-2(n)H-3 &Tertiary fission

Iodine Nuclides

Nuclide	Half-life	% fission yield
I-134	52.3 minutes	7.176
I-132	2.28 hours	4.127
I-135	6.7 hours	6.386
I-133	20.8 hours	6.762
I-131	8.06 days	2.774

Fission Gases

Nuclide	Half-life	% fission yield
Xe-138	14.2 minutes	6.235
Kr-87	76 minutes	2.367
Kr-88	2.79 hours	3.642
Kr-85m	4.4 hours	1.332
Xe-135	9.16 hours	6.732
Xe-133	5.26 days	6.776

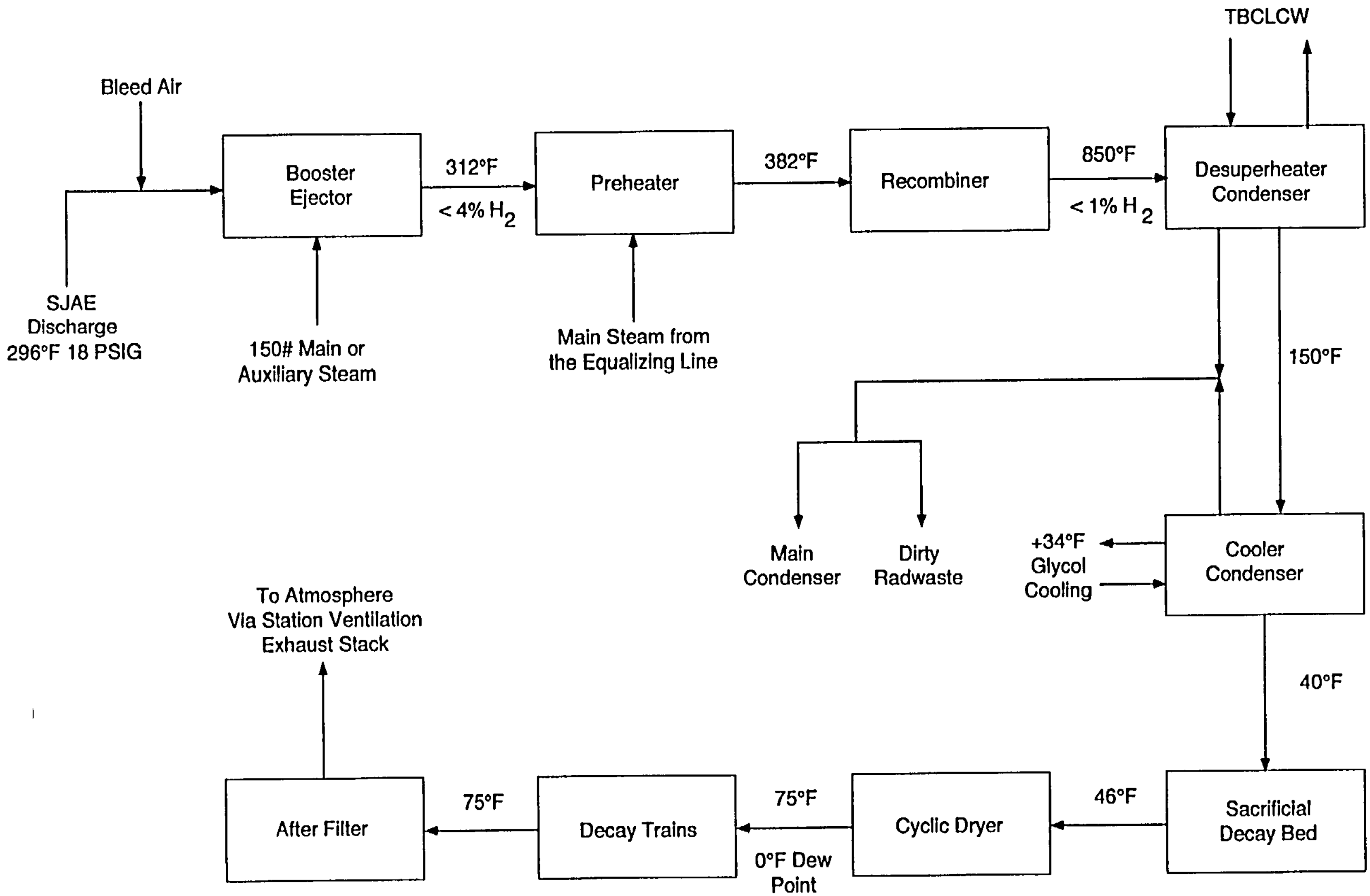

Figure 8.1-1 Offgas System Block Diagram

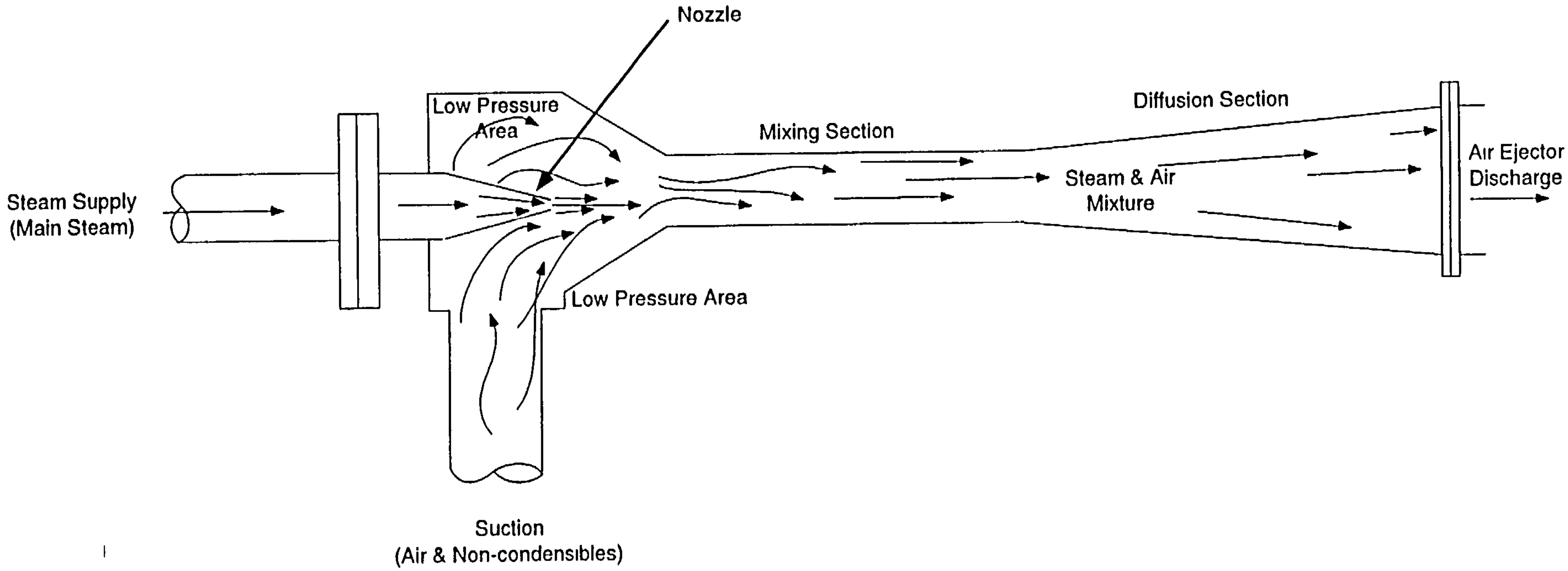

Figure 8.1-2 Air Ejector Internal Flowpaths

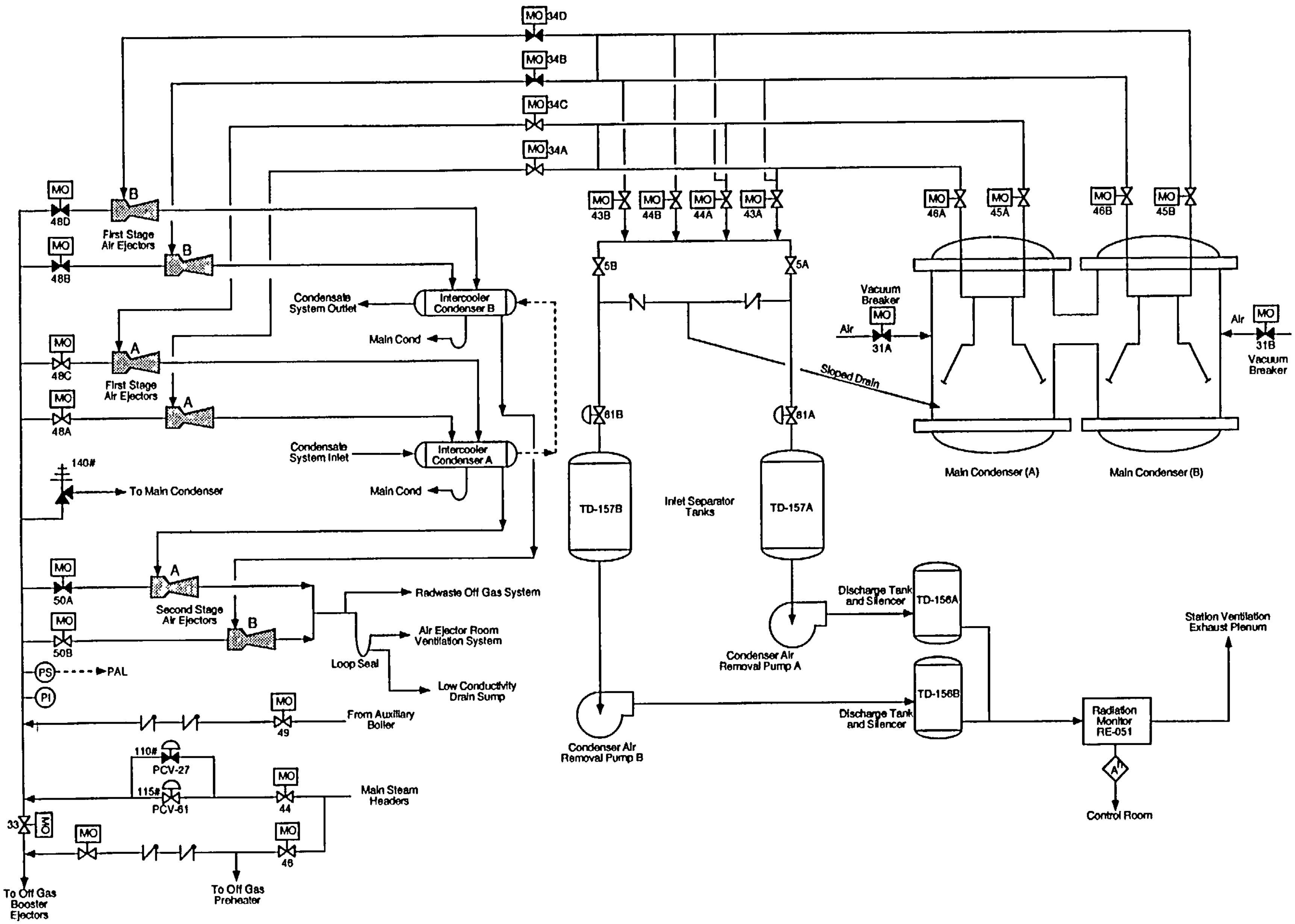

Figure 8.1-3 Condenser Air Removal

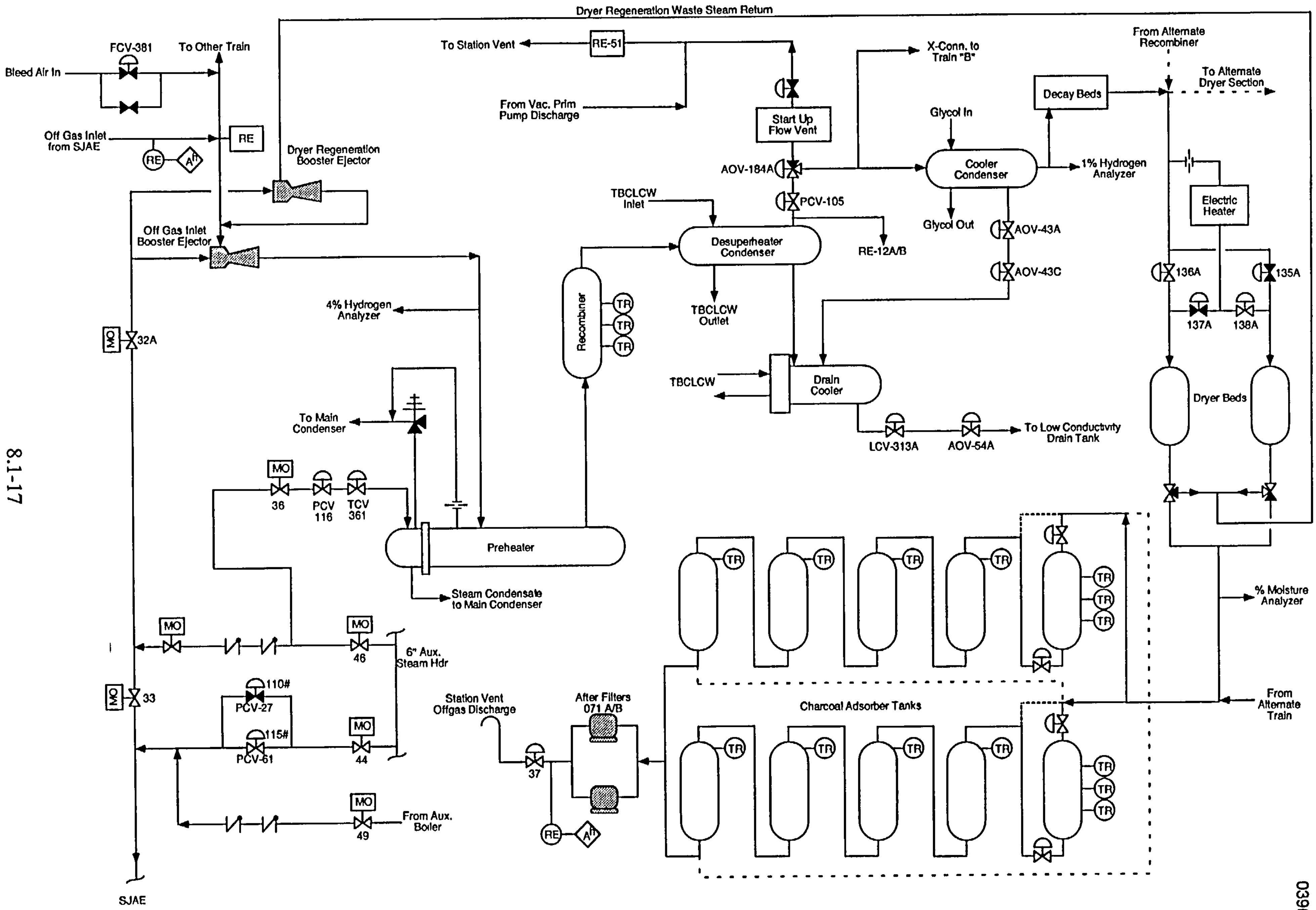

Figure 8.1-4 Offgas System

Boiling Water Reactor
GE BWR/4 Technology
Technology Manual

Chapter 8.2

Liquid Radwaste System

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8.2 LIQUID RADWASTE SYSTEM

Learning Objectives:

1. State the System's purposes.
2. List the four (4) classifications of liquid radwaste.
3. Place major system components in flow path order and explain the purpose of each for the following systems:
   a. Waste Collector System
   b. Floor Drain Collector System
   c. Chemical Waste System
   d. Detergent Waste System
4. Explain the batch release concept as applied to liquid radwaste.

8.2.1 Introduction

The purposes of the liquid radwaste system are:

1. To collect, process, and return radioactive liquid waste to the plant for reuse.

2. To allow for batch discharge of liquid radwaste to the environment in such a manner that 10 CFR 20 radionuclide concentaration standards are not exceeded and dose commitments of 40 CFR 142 and effluent techical specifications are not exceeded.

The Liquid Radwaste System collects, processes, and returns radioactive liquid waste to the plant for reuse and disposes of liquid waste not suitable for reuse.

In addition, the liquid radwaste system allows for batch discharges of liquid radwaste to the discharge canal (environs) in such a manner that 10 CFR 20 radionuclide concentration standards are not exceeded and dose commitments of 40 CFR 142 and effluent technical specifications are not exceeded.

The functional classification of the Liquid Radwaste System is that of a power generation system.

8.2.2 System Description

The liquid radioactive wastes are classified, collected, and treated as either high purity, low purity, chemical, or detergent wastes. The terms high purity and low purity refer to conductivity and not radioactivity. These liquid radwastes are often referred to as CRW (clean radwaste) and DRW (dirty radwaste).

All liquid streams passing through a BWR have the potential of bein contaminated. The disposal method is determined by the type of contamination and the level of contamination.

The Liquid Radwaste System is divided into several subsystems so that the liquid wastes from various sources can be kept segregated and processed separately. Cross connections between the subsystems provide additional flexibility for processing of the wastes by alternate methods. Included in the Liquid Radwaste System are the following subsystems: Waste Collector System, Floor Drain System, Chemical Waste System, Radwaste Evaporator System, and Detergent Waste System. The first point in the collection of liquid waste takes place in collection tanks or sumps located throughout the plant buildings. The drain sumps are arranged and piped to the radwaste subsystems for processing according to their classification.

The Liquid Radwaste System is designed so that the liquid radioactive wastes which are discharged from the plant are always within the radionuclide concentration limits specified in 10 CFR 20, Appendix B, Table II, Column 2, and the operation or availability of the plant is not limited and so that radiation exposures are within the guidelines of 40 CFR 141 and the calendar dose commitments of the effluent technical specifications.

8.2.2.1 Waste Collector System Descri ption

High purity (low conductivity) liquid wastes are collected and processed in the Waste Collector System from the following sources:

- Drywell equipment drain sump
- Containment equipment drain sump
- Auxiliary building equipment drain sump
- Fuel building equipment drain sump
- Radwaste building equipment drain sump
- Turbine building equipment drain sump
- Reactor Water Cleanup System
- Residual Heat Removal System
- Decantate from cleanup phase separators
- Decantate from condensate phase separators
- Waste package drain tank
- Offgas condensate collector sump
- Turbine building condensate pump pit equipent drain sumps
- Standby Gas Treatment System sumps

The high purity wastes are processed, as shown in Figure 8.2-2, by filtration and ion exchange through the waste filter and waste demineralizer. After processing, the waste is pumped to waste sample tanks where it is sampled and then, if satisfactory for reuse, transferred to the condensate storage tank as makeup water.
If the analysis of the sample reveals water of high conductivity (>1 umho/cm) or high radioactivity concentration (>10^{-3}uCi/cc), it is returned to the system for additional processing. These wastes may be released to the discharge canal if allowable discharge canal concentrations are not exceeded.

8.2.2.2 Floor Drain Collector System Description

Low purity (high conductivity) liquid wastes are collected and processed, as shown in Figure 8.2-3 in the Floor Drain Collector System from the following sources:

- Drywell floor drain sump
- Containment floor drain sump
- Auxiliary building floor drain sump
- Fuel building floor drain sump
- Radwaste building floor drain sump
- Turbine building floor drain sump
- Chemical waste tank
- Turbine building condensate pump pit floor drain sump
- Residual Heat Removal System
- Radwaste backwash and receiver pit floor drain sump

These waste generally have low concentrations of radioactive impurities; therefore, processing consists of filtration and subsequent transfer to the floor drain sample tank for sampling and analysis. From the floor drain sample tanks, the liquid waste can be batch transferred to the circulating water discharge canal for dilution and discharge off site or to the Waste Evaporator System which is the preferred route. In the Waste Evaporator System, the liquid waste is distilled. The concentrates from the waste evaporator are packaged in containers for disposal in an off site burial ground. The distillate is collected and routed to the condensate storage tank as makeup water or to the Waste Collector System for further processing.

8.2.2.3 Chemical Waste System Description

Chemical Wastes, shown in Figure 8.2-3, are collected in the chemical waste tank from the following sources:

- Shop decontamination solutions
- Laboratory drains
- Reactor building and turbine building decontamination drains
- Chemical waste from waste cleanup and condensate precoat tanks

These chemical wastes are of such high conductivity as to preclude treatment by ion exchange. The radioactivity concentrations are variable and are substantially affected by the use of decontamination solutions and by the amount of fission product radioactivity present. Normally, the radioactivity concentrations are low enough to meet discharge canal concentration limits (after dilution), and these wastes may be processed by filtration and dilution in the same manner and with the same equipment as the low purity wastes.

If the activity of these wastes is too high for canal discharge, the wastes are put in drums and solidified by use of an absorbent material.

8.2.2.4 Radwaste Evaporator System Description

The Radwaste Evaporator System, shown in Figure 8.2-4, is designed to distill liquid wastes fed to it by the floor drain sample pumps. Distillation is achieved using steam from the auxiliary boiler system and cooling water from the Station Service Water System.

The distillate is collected in either one of two distillate tanks. When one distillate tank is full, the distillate flow from the evaporator is routed to the other tank. The contents of the full tank are circulated, sampled, and analyzed. If the distillate meets condensate standards, it is sent directly to the condensate storage tank (CST). If not, it is routed to the waste collector tank for further processing through the waste demineralizer before being sent to the CST. If there is insufficient room in the CST, the liquid is released to the circulating water discharge conduits for dilution before discharge.

The concentrate from the evaporator is continuously fed to the concentrate holding tank where it is held until sufficient quantity is accumulated. The concentrate is then homogenized by recirculation and withdrawn by the chemical solidification equipment. The concentrate and solidification chemicals are then pumped to the radwaste packaging area and into a disposal cask.

8.2.2.5 Detergent Waste System Description

Detergent wastes, shown in Figure 8.2-5, are collected in the laundry drain tanks. These wastes are primarily from radioactive laundry operations and decontamination solutions which contain detergents. Detergent wastes are of low radioactivity concentration 10^{-5}uCi/ml). Because these wastes will foul ion exchange resins, they are kept separate. Detergent wastes are sampled, filtered through the laundry drain filter, and discharged into the circulating water discharge canal at such a rate that the release limits are not exceeded.

Cask decontamination liquid is collected in the 15,000 gallon cask decontamination tank. This liquid is essentially high conductivity water of low radioactivity concentration (<10^{-5}uCi/ml).

The liquid is sampled, filtered through the laundry drain filter, and discharged into the circulating water canal.

8.2.3 Component Description

The major components of the Liquid Radwaste System are discussed in the paragraphs that follow.

8.2.3.1 Waste Collector System

The Waste Collector System includes the following components:

- 38,000 gallon waste collector tank
- 440 gpm waste collector pump
- 75,000 gallon waste surge tank
- 440 gpm waste surge pump
- 200 ft^2waste collector filter and holding pump
- 125 ft^3 waste demineralizer
- 19,000 gallon waste sample tanks (4)
- 440 gpm waste sample pumps (2)

The waste collector tank receives effluent from the sources shown in Figure 8.2-1. The waste surge tank can receive effluent from the Reactor Water Cleanup (RWCU) System, Residual Heat Removal (RHR) System or off standard recycle from the waste demineralizer. The waste collector and waste surge pumps are identical, each drawing suction from its respective tank. A suction line cross connection and normally closed manual valve allow either pump to draw suction from the opposite tank. Each tank has a level indicator with high/low level alarms, and a low level pump cutout switch for each tank will trip its respective pump. If a pump is valved to draw suction from the opposite tank, the low level trip for that tank will protect the pump that is in use. The waste collector filter receives effluent from either the waste collector or waste surge pump. It removes suspended solids and passes the effluents to the waste demineralizer. The waste collector filter is equipped with a precoat holding pump to hold the precoat on the filter tubes when the filter is not in use. The waste demineralizer is a mixed bed type demineralizer that further removes impurities from the waste stream. The waste demineralizer effluent conductivity is monitored and is automatically routed to the waste sample tanks (if less than 1.0 umho) or back to the waste collector or waste surge tank (if greater than 1.0 umho). The waste sample tanks serve as a collection and monitoring point for processed wastes before returning them to the condensate storage tank. An alternate flow path is available to route the water to the discharge canal.

Waste Collector Tank

The waste collector tank is a stainless steel, cylindrical vessel with a capacity of 38,000 gallons and a working volume of 34,000 gallons. The bottom of the tank is flat with a 6 inch diameter outlet connected to the waste collector pump. The top of the tank is covered and has a 6 inch diameter vent outlet connected to the radwaste building exhaust. The tank is equipped with drain inlets, overflow lines and drain lines, and mixing eductors. A manhole is provided for cleaning and inspection.

Waste Collector Pump

The waste collector pump is a 440 gpm centrifugal unit. Pump and valve controls are located in the radwaste control room. The pump takes a suction from the waste collector tank.

Waste Surge Tank

The waste surge tank is a stainless steel, cylindrical vessel with a capacity of 75,000 gallons and a working volume of 65,000 gallons. The bottom of the tank is flat with a 6 inch diameter outlet connected to the waste surge pump. The top of the tank is covered and has a 6 inch diameter vent outlet connected to the radwaste building exhaust. The tank is equipped with drain inlets, overflow lines and drain lines, and mixing eductors. A manhole is provided for cleaning and inspection.

Waste Surge Pump

The waste surge pump is a 440 gpm centrifugal unit taking a suction from the waste surge tank. Pump control and valve controls are located in the radwaste control room.

Waste Collector Filter

The collector filter is a pressure precoat filter consisting of a dished head pressure vessel with a removable flanged top section. Perforated tubes (called septa), covered with a fine stainless steel screen, are rigidly suspended from a tube plate which is supported at the vessel flange. The screened tubes serve to collect and support the Solka Floc filter precoat. The filter is provided with a holding pump to keep the filter cake in place when flow through the filter from the waste pumps is not present. The holding pump recirculation flow passes through an air cooler to maintain recirculation water temperature less than 140°F.

The filter tubes are precoated by depositing a layer of Solka Floc on the perforated tubes. A fixed amount of Solka Floc in a slurry is recirculated from the precoat system through the filter to form a cake on the filter tubes. The Solka Floc particles bridge the openings in the filter tube screen and form a microscopically fine sieve, much finer than the filter tube screen itself could provide.
Solka Floc is a filter medium manufactured by Brown Paper Co., Inc. It is a fibrous cellulose material similar to paper stock. (Fibers are less than 1/64 inch long and approximately 0.0005 inch in diameter).

Recirculation of the Solka Floc continues until the filter tubes are completely coated, as indicated by recirculation stream clarity in flow sight glass. Used Solka Floc precoat is removed by using plant service air to dislodge the precoat from the tubes and by using condensate to backwash the loose precoat out the bottom of the filter vessel and to the waste backwash receiving tank. Filter condition is indicated by high differential pressure (DP) across the filter vessel, which gives a high dP annunciator at the radwaste control panel.

The waste collector filter has a design operating pressure of 150 psi and 200 ft^2 of filter area.

Waste Demineralizer

The waste demineralizer is a vertical cylindrical dished head pressure vessel with a conical bottom, which contains 125 ft^3 of mixed cation and anion resins. It is sized to provide adequate head space for mixing and settling replacement resin. Filtered water enters through the top of the demineralizer and is distributed across the surface of the resin bed by an inlet header with multiple spray heads. The demineralized water is collected by a stainless steel underdrain and discharges through the bottom of the demineralizer. New resins can be added via the resin fill line. Expended resins are discharged to the spent resin tank as a water slurry by pressurizing the uppermost portion with air. Demineralizer and resin condition is indicated by pressure differential indicator and effluent conductivity monitor.

Waste Sample Tanks

There are a total of four waste sample tanks. The piping is arranged so that two waste sample tanks are connected in parallel, via a three-wa valve, to receive effluent from the waste demineralizer. Each tank is a stainless steel vessel with a capacity of 19,000 gallons and a working volume of 17,000 gallons. The bottom of the tank is equipped with a 6 inch diameter waste sample pump suction. The top of the tank is covered and has a 6 inch diameter vent outlet connected to the radwaste building exhaust. Flanged connections are provided for overflow, outlet, level sensor lines, and mixing eductors. Tank levels are monitored in the radwaste control room. High and low level alarms and low level waste sample pump cutoff are provided.

Waste Sample Pumps

There are two waste sample pumps, each taking a suction from one set of parallel connected waste sample tanks. A cross connection and manual valve between the waste sample tank outlet lines allows either pump to draw from any tank. Both pumps are 440 gpm centrifugal units with pump control in the radwaste control room. The pumps normally discharge (after sampling) to the condensate storage tank. Alternate discharge paths are to the waste collector or surge tanks (off standard recycle) or to the discharge canal via the floor drain collector system and radwaste discharge radiation monitor.

8.2.3.2 Floor Drain Collector System

The Floor Drain Collector System includes the following components:

- 32,000 gallon floor drain collector tank
- 84 gpm floor drain collector pumps (2)
- 200 ft^2 floor drain filter and precoat holding pump
- 16,000 gallon floor drain sample tanks(2)
- 84 gpm floor drain sample pumps (2)
- discharge control station

The floor drain collector tank receives effluent from the sources shown in Figure 8.2-2. The floor drain collector pump draws suction from the floor drain collector tank and normally discharges through the floor drain filter to the floor drain sample tanks. The floor drain collector tank is equipped with a level sensor and low level interlock with the floor drain collector pump. The floor drain filter normally receives effluent from the floor drain collector tank with a cross connection to the suction side of the waste collector filter.

The cross connection allows either filter to be used as a backup or alternate as needed. The floor drain filter is equipped with a precoat holding pump to hold the precoat on the filter tubes when the filter is notin use.

Filtered waste from the floor drain filter normally passes to the two floor drain sample tanks. The tanks are connected in parallel through an air operated, three-way valve. An alternate path exists to the waste collector tank which is interlocked with a conductivity element. Waste water is allowed to pass to the waste collector tank if conductivity is less than 1 mmho. The floor drain sample tanks provide suction for two floor drain sample pumps piped in parallel.

The cross connected tanks have a level indicator with a high/low level alarm and a low pump cutout switch which will trip the in service pump. Effluent from the floor drain sample tanks can be routed to the discharge canal, the waste collector tank, or the radwaste evaporator. The preferred flow path is to the radwaste evaporator where the liquid waste is distilled with the distillate going to the condensate storage tank (CST) and the concentrate to the solid waste packaging system. If the condensate storage tanks are full, the water is released at a controlled rate directly to a discharge canal where it is diluted with circulating water as a liquid discharge. Routing the water to the waste collector tank is done to process the water through the waste filter and demineralizer and return it to the CST.

Floor Drain Collector Tank

The floor drain collector tank is a stainless steel, cylindrical vessel with a capacity of 32,000 gallons and a working volume of 29,000 gallons. The bottom of the tank is flat with a 6 inch diameter outlet connected to the floor drain collector pumps. The tank is vented to the radwaste building exhaust and overflows to the chemical waste tank. Tank level is monitored in the radwaste control room. A manhole is provided for cleaning and inspection.

Floor Drain Collector Pumps

The floor drain collector pumps are 84 gpm centrifugal units each drawing a suction from the floor drain collector tank and normally discharging through the floor drain filter to the floor drain collector tanks. Pump and valve controls are located in the radwaste control room.

Floor Drain Filter

The floor drain filter is similar to the waste collector filter and has an identical holding pump and air cooler system. Filter precoat is supplied by a common precoat system. The floor drain filter effluent flows to the two floor drain sample tanks via an air operated, three-way valve controlled from the radwaste control room.

Floor Drain Sample Tanks

The floor drain sample tanks are piped in parallel to receive effluent from the floor drain filters. The tanks are similar to the waste sample tanks. Each tank has a capacity of 16,000 gallons and a working volume of 14,500 gallons. The tanks are cross connected with an equalizer line. A suction line cross connection allows either sample pump to draw from either sample tank.

Floor Drain Sample Pumps

There are two floor drain sample pumps, each taking a suction on both floor drain sample tanks. Both pumps are 84 gpm centrifugal units. Pump and valve control is from the radwaste control room. The pumps have the capability of discharging to the discharge canal via the discharge control station and radiation monitor or to the radwaste evaporator for further treatment or to the waste collector tank before returning to the condensate storage tank.

Discharge Control Station

The discharge control station consists of two flow control valves. One valve is used for high flow rates (0 - 100 gpm) and the other is used for low flow rates (0 - 10 gpm). The discharge flow rate and the flow control valve used are determined by the activity in the floor drain sample tanks and the available dilution flow from the circulating water pumps.

8.2.3.3 Chemical Waste System

The Chemical Waste System includes the following components:

- 5000 gallon chemical waste tank
- Chemical reagent additive tank
- 26 gpm chemical waste pumps (2)

The chemical waste tank receives effluent from the sources shown in Figure 8.2-3. The chemical waste pumps draw a suction from the chemical waste tank and discharge to the floor drain collector tank.

The pumps are also used to recirculate the tank contents while chemical additives or coagulating agents are added to neutralize waste or to precipitate solids. Once in the floor drain collector tank, the waste is processed through the floor drain collector system. An alternate disposal method is provided by a drum filling connection. If samples indicate that the chemical waste tank contents cannot be safely transferred, they may be pumped to drums and solidified by use of an absorbent material.

Chemical Waste Tank

The chemical waste tank is a stainless steel vessel with a capacity of 5000 gallons and a working volume of 4500 gallons. The bottom of the tank is equipped with a 2 inch diameter outlet connected to the chemical waste pumps. The tank is vented to the radwaste building exhaust duct and overflows to the floor drain sump. The tank level is monitored in the radwaste control room. Mixing eductors are used in recirculating the tanks contents.

Chemical Reagent Additive Tank

The chemical reagent additive tank is used to add acid or caustic to the chemical waste tank. It has a 10 gallon capacity with a connection from the demineralized water system. Chemicals are mixed with demineralized water and are gravity fed to the chemical waste tank.

Chemical Waste Pumps

There are two chemical waste pumps, each drawing suction from the chemical waste tank. Each pump is a 26 gpm centrifugal unit. Pump and tank level controls are interlocked to allow low level cutoff of the operating pump. Normally, the pumps discharge to the floor drain collector tank but there are alternate discharge paths; a drum filling station allows for disposal of solid waste and the discharge canal can receive liquid radwaste.

8.2.3.4 Radwaste Evaporator System

The Radwaste Evaporator System includes the following components:

- 30 gpm waste evaporator
- 10,000 gallon distillate tanks (2)
- 80 gpm distillate tank pumps (2)
- 1400 gallon concentrate holding tank concentrate pump
- Solid waste packaging system

The radwaste evaporator receives effluent from the floor drain sample tanks as shown in Figures 8.2-3 and 8.2-4.

The waste water is first pumped through the heating element which receives heating steam from the auxiliary boiler. It then flows to the vapor body where it is continuously recirculated through the vapor body and heating element.

The heating element heats the waste water to near the boiling point, after which it flows to the vapor body. The vapor body is held at a slightly lower pressure than the heating element, thus permitting the waste liquid to boil. The vapor from the boiling liquid passes through steam separator pads (located within the vapor body) and flows to the surface condenser. In the surface condenser, the vapor is condensed to a distillate which is pumped to one of the two distillate tanks. From here, the distillate tank pumps normally transfer the water to the condensate storage tank. Alternate flow paths are available to the waste collector tank for further processing or to the discharge canal.

As the evaporation process in the vapor body continues, the density of the liquid circulating through the vapor body and the heating element increases. When this concentrate reaches a preset density, it must be eliminated from the system. This is accomplished by a discharge line provided at the bottom of the vapor body. Under normal operating conditions, the concentrate is discharged automatically after a predetermined specific gravity has been reached. The discharge valve opens to a predetermined position and when the specific gravity decreases, the discharge valve closes. During this discharge process, the concentrate is dumped to the concentrate holding tank and processed out as solid waste.

Radwaste Evaporator

The radwaste evaporator is a single effect evaporation unit using a vapor separation tank. It incorporates a two pass, horizontal tube, heating element with forced circulation. The evaporator has a 30 gpm capacity and is made up of:

- heating element
- 50 gpm condensate pumps (2)
- vapor body
- 2300 gpm recycle pump
- surface condenser
- after condenser
- 50 gpm distillate pumps (2)

Steam is supplied to the shell side of the heating element from the auxiliary boiler or the main steam system. The steam heats the water being pumped from the floor drain sample tanks to the evaporator. The condensed heating steam collects in the bottom of the heating element and is pumped back to the auxiliary boiler by the condensate pumps. A flow control valve on the discharge of the pumps regulates the level within the heating element.

There are two condensate pumps each drawing a suction from a collection point on the shell side of the heating element. Each pump is a 50 gpm centrifugal unit. The discharge of the pumps is directed through a common flow control valve which is controlled by the level within the heating element. A low level shutdown is also provided for pump protection. The common discharge line returns the condensate to the auxiliary boiler.

The heated waste water enters the vapor body after leaving the heating element. The flow rate to the heating element, and in turn the vapor body, is controlled by the level within the vapor body. The connecting pipe between the heating element and the vapor body is designed to impose a back pressure on the heating element tubes. Thus, boiling is suppressed in the tubes. Heat release occurs as flash evaporation in the vapor body. As the liquid enters the vapor body, vapors are released which travel up and pass through an entrainment separator for removal of entrained particles.

The vapor exits the separator section and goes to the surface condenser. As the boiling process continues within the vapor body, the concentration of dissolved solids increases. The density of the liquid is monitored and is used to control the continuous discharge or blowdown mode of operation. When the specific gravity of the liquid reaches 1.24, the concentrate discharge valve is opened 35% and the liquid is pumped to the concentrate holding tank. All other portions of the evaporator operate normally. When the specific gravity drops to 1.22, the discharge valve is closed. A batch discharge mode goes into automatic operation if the specific gravity reaches 1.28. During this mode, the evaporator is essentially shut down, discharge steam is applied to the vapor body and the concentrate discharge valve is opened 50% dumping the concentrate to the holding tank.

The recycle pump is a 2300 gpm centrifugal unit. It draws a suction on the bottom of the vapor body and discharges through the heating element back to the vapor body. The recycle pump provides continuous recirculation of the liquid within the evaporator. Forced circulation results in a much higher coefficient of heat transfer which can result in more efficient construction and operation. The recycle pump is also used in the continuous discharge mode to pump the concentrates from the vapor body to the holding tank.

The surface condenser is a shell and tube heat exchanger receiving cooling water from the Station Service Water system. Steam from the vapor body is directed to the condenser, the steam condenses on the tubes and collects in a small reservoir in the bottom of the condenser shell. The condensate is then transferred to the distillate tank by the distillate pumps. Level in the surface condenser is conrolled by a level control valve on the discharge of the distillate pumps. The conductivity of the water leaving the condenser is monitored and directs the flow from the distillate pumps back to the vapor body if the conductivity is excessively high.

The ejector receives steam from the auxiliary boiler and draws a suction on the shell side of the surface condenser. Its purpose is to remove noncondensible gases that accumulate in the surface condenser just as the air ejectors remove noncondensibles from the main condenser. The ejector exhausts to the after condenser where the steam is condensed and the gases are vented to the radwaste building exhaust duct.

The after condenser is a shell and tube heat exchanger. Steam from the ejector is exhausted to the shell side and cooling water from the Station Service Water system is passed through the tubes condensing the steam. The condensed steam flows by gravity to the condensate receiver where a level control switch regulates a level control valve. When the valve opens, condensate is returned to the suction side of the recycle pump. The condensate receiver is also vented to the radwaste building exhaust duct.

Two distillate pumps each draw a suction on the shell side of the surface condenser. Each pump is a 50 gpm centrifugal unit discharging to either of two distillate tanks. A level control valve on the discharge of the pumps is used to regulate flow to the distillate tanks by controlling level in the surface condenser. High conductivity in the suction to the pumps will direct the flow back to the vapor body instead of to the distillate tanks.

Distillate Tanks

Each distillate tank is a stainless steel vessel with a capacity of 10,000 gallons. The distillate tanks receive effluent from the radwaste evaporator and are arranged so that one is filling while the other is being pumped out by the distillate tank pumps.

The distillate tanks overflow to the floor drain sump and are vented to the radwaste building exhaust duct. The tanks are equipped with level monitors which initiate alarms on high and low levels and provide pump shutdown for low level conditions.

Distillate Tank Pumps

Two distillate tank pumps each draw a suction on the distillate tanks. The pump suctions are cross connected so that either pump can draw from either tank. Each pump is an 80 gpm centrifugal unit with low distillate tank shut down protection.

Concentrate Holding Tank

The concentrate holding tank has a capacity of 14,000 gallons. It receives the concentrate blowdown from the vapor body of the radwaste evaporator. The tank is equipped with an internal electric heater. The heater maintains the temperature at 90°-110°F. A holding pump of 20 gpm capacity is used to circulate the tank contents. The concentrate holding tank is vented to the radwaste building exhaust duct and a 1 inch outlet line connects to the concentrate pump.

Concentrate Pump

The concentrate pump is a 20 gpm centrifugal unit taking suction from the concentrate holding tank. The pump and its suction and discharge line are electrically heated to maintain fluid temperature at 90°-110°F. The pump transfers batches of concentrated waste to the solid waste packaging system. The pump is flushed with heated condensate after each use.

Solid Waste Packaging System

The solid waste packaging system for the radwaste evaporator consists of a tigerlock tank containing a drying agent, a tigerlock pump, catalyst tank and pump, and a solid waste packaging hookup with shipping containers.

The concentrate is pumped from the holding tank into the shipping container along with the drying agent and catalyst. The filling connections are removed and the container is stored in the waste package room while awaiting shipment.

Further information on the solid waste packaging system is contained in Section 8.3.

8.2.3.5 Detergent Waste System

The Detergent Waste System includes the following components:

- 15,000 gallon cask decontamination collector tank
- 1100 gallon laundry drain tanks (2)
- 26 gpm laundry drain pumps (2)
- laundry drain filter

The cask decontamination solution tank and laundry drain tanks receive effluents from the sources shown in Figure 8.2-5. The laundry drain pumps are connected in parallel to take a suction from either laundry drain tank or the cask decontamination collector tank. The laundry drain pumps discharge to the laundry drain filter, where the waste is filtered on the way to the discharge canal via the floor drain collector system and radiation monitor.

Cask Decontamination Collector Tank

The cask decontamination collector tank is a cylindrical steel vessel with a capacity of 15,000 gallons. The bottom of the tank is flat with a 3 inch diameter outlet connected to the laundry drain pumps. The tank is vented to the radwaste building exhaust duct and overflows to the laundry drain tanks.

Laundry Drain Tanks

The two identical laundry drain tanks are cylindrical 1100 gallon stainless steel vessels. Each tank is vented to the radwaste building exhaust duct and overflows to the floor drain sump. Tank level is monitored and initiates high and low level alarms and pump cutout on low level. The recirculation return line for each tank is connected through air operated valves to a common pump discharge header recirculation line.

Laundry Drain Pumps

The two laundry drain pumps are 26 gpm centrifugal units drawing suction from the laundry drain tanks and cask decontamination collector tank. A pump suction cross connection allows either pump to draw suction from any tank.

Laundry Drain Filter

The laundry drain filter consists of a pressure vessel containing removable disposable cartridges, available with different pore sizes, which can be changed to suit different filtering requirements. They are removed and discarded when the differential pressure indicates their end of life has been reached. Differential pressure is indicated on the radwaste panel with a high alarm. The filter effluent is directed to the floor drain collector system where it is monitored and released to the discharge canal.

8.2.4 System Features and Interfaces

A short discussion of system features and interrelations between this system other plant systems is given in the paragraphs that follow.

8.2.4.1 Normal Operation

The Liquid Radwaste System is designed to be operated on a continual batch treatment basis, under manual control, to permit the operator flexibility in scheduling and processing the varying types and quantities of wastes. Automatic and semiautomatic control features are provided to assist the operator in certain processing operations. Monitoring, recording, and control of almost all the radwaste components are accomplished from the radwaste control room which is located in the radwaste building. Additional control stations for selected systems are located near the associated equipment.

8.2.4.2 Liquid Radwaste Discharges

Under optimum conditions, waste water from the floor drain collector and waste collector systems are cycled after processing back to the condensate storage tanks; however, optimum conditions frequently may not be present. For example, scheduled and unscheduled outages are sources of waste water which can easily exceed the design output of the liquid radwaste system. Under these conditions, batch releases of treated waste water are made to the discharge canal to correct the water inventory in balance.

Liquid radwaste discharges cannot exceed the radionuclide concentration specified in 10 CFR 20, Appendix B, Table II, Column 2. In addition, the dose contributions from liquid radwaste discharges cannot exceed 1.5 millirem to the whole body and 5 millirem to any organ during any calendar quarter (3 millirem whole body and 10 millirem to any organ per calendar year) per effluent technical specifications and 40 CFR 141.

Before discharge, the waste sample tanks or floor drain sample tanks are sampled as batches and analyzed by gamma-ray spectroscopy. If the analysis results do not exceed 10 CFR 20 and the cumulative dose commitment for the calendar quarter as determined by the Offsite Dose Program, the discharge can be made. The pumpout rate of the waste sample tanks or the floor drain sample tanks is variable the maximum rate is 80 gpm. There is a scintillation process radiation monitor (PRM) on the discharge line to the canal which indicates count rate. The PRM will alarm at a setpoint determined from the Offsite Dose Program. It will also isolate the discharge line when the countrate has exceeded the radionuclide concentration that would exceed 10 CFR 20 or technical specifications (the exceeding of the calendar quarter dose commitment), as determined by the radionuclide analysis and offsite dose calculation analysis. All records of all liquid radwaste discharges are kept for the life of the plant. These records include radionuclide analysis results, the Offsite Dose Calculation, tank volume, pumpout rate, and PRM readings.

8.2.4.3 System Interfaces

A short discussion of interfaces this system and has with other plant systems is given in the paragraphs that follow.

Closed Cooling Water System (Section 11.1)

The Closed Cooling Water (CCW) System provides cooling water to equipment sumps and components.

Process Radiation Monitoring System (Section 8.4)

The Process Radiation Monitoring (PRM) System monitors Liquid Radwaste System discharges to the environment.

Circulating Water System (Section 11.3)

The Circulating Water System supplies dilution flow for liquid waste discharges.

Station Service Water System (Section 11.4)

The Station Service Water System supplies cooling water to the surface condenser and after condenser of the radwaste evaporator.

Solid Radwaste System (Section 8.3)

The Solid Radwaste System accepts filter sludges and spent resins from the Liquid Radwaste System.

Auxiliary Boiler System (No section in manual)

The Auxiliary Boiler System supplies steam to the radwaste evaporator.

8.2.5 BWR Differences

The discussion in this section is appropriate for any BWR of product lines BWR/2 through BWR/6. However, major differences exist at facilities, even facilities of the same product line. The differences are, to a large degree, a function of the architect engineer chosen by the utility.

8.2.6 Summary

Classification - Power generation system

Purpose - To collect, process, and return radioactive liquid waste to the plant for reuse and to dispose of liquid waste not suitable for reuse

Components - Waste Collector System, Floor Drain Collector System, Chemical Waste System, Radwaste Evaporator System, Detergent Waste System

System Interfaces - CCW System, PRM System, Circulating Water System, Station Service Water System Solid Radwaste System, Auxiliary Boiler System

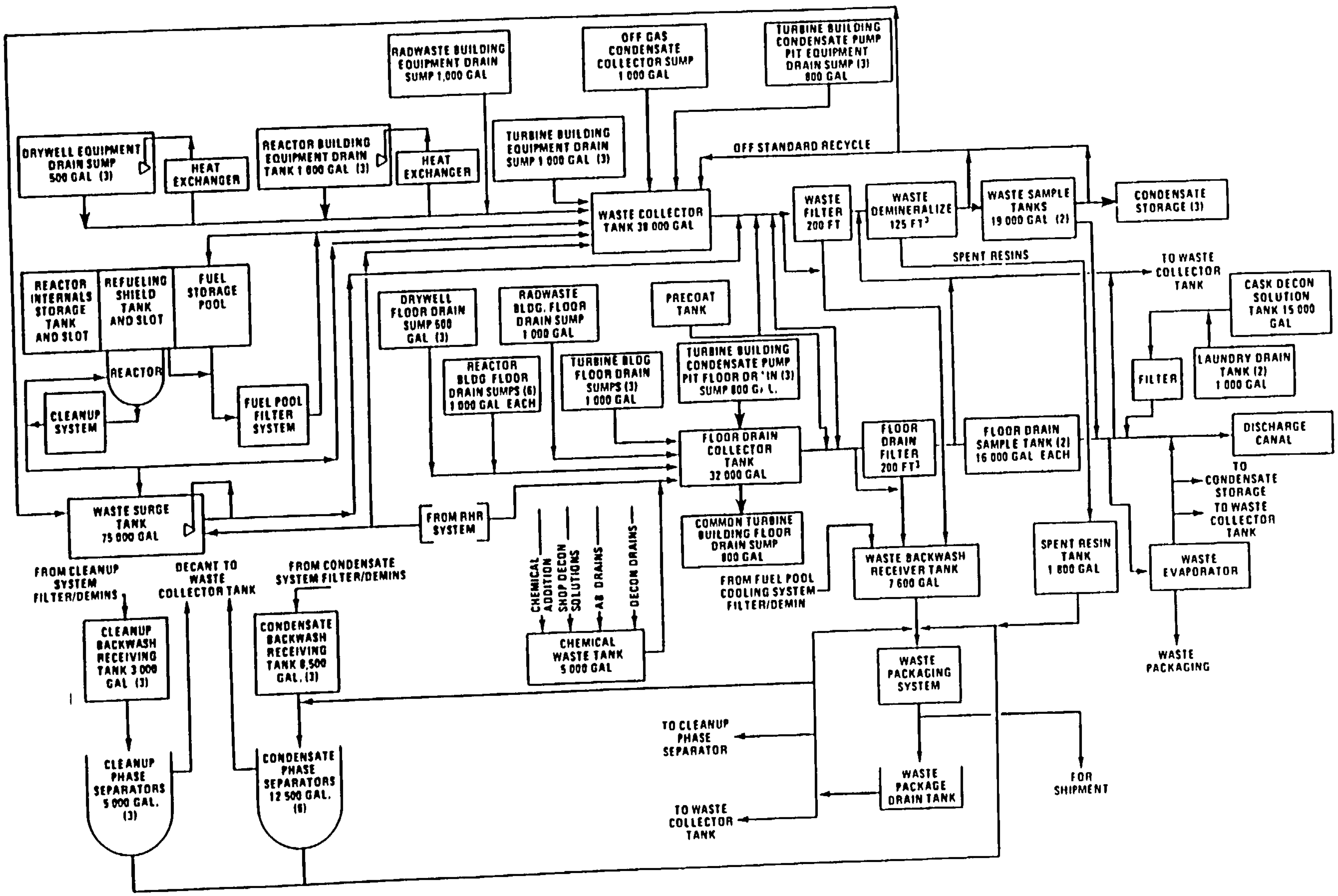

FIGURE 8.2 – 1 LIQUID RADWASTE SYSTEM

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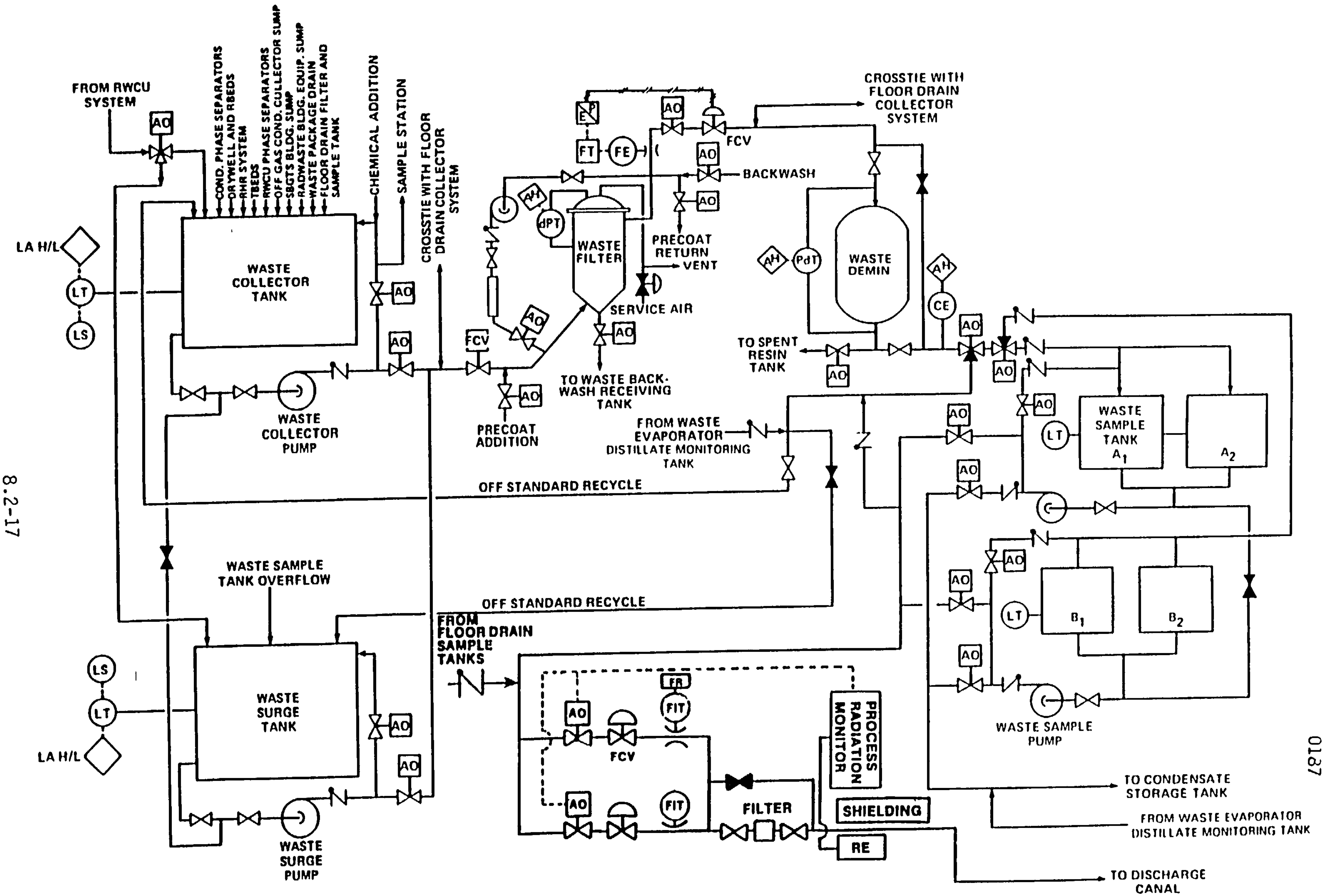

FIGURE 8.2–2 WASTE COLLECTOR SYSTEM

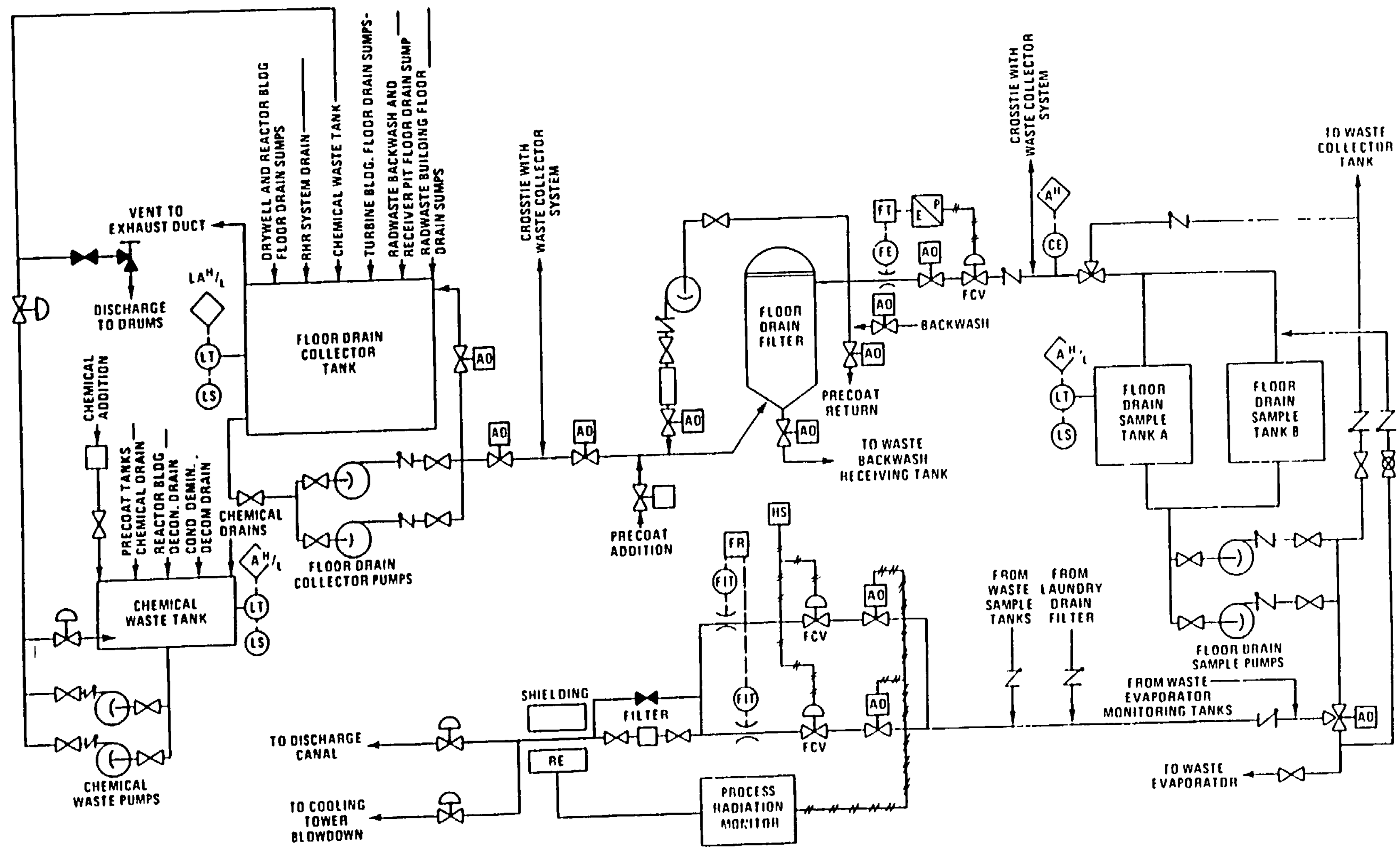

FIGURE 8.2 -- 3 FLOOR DRAIN COLLECTOR SYSTEM

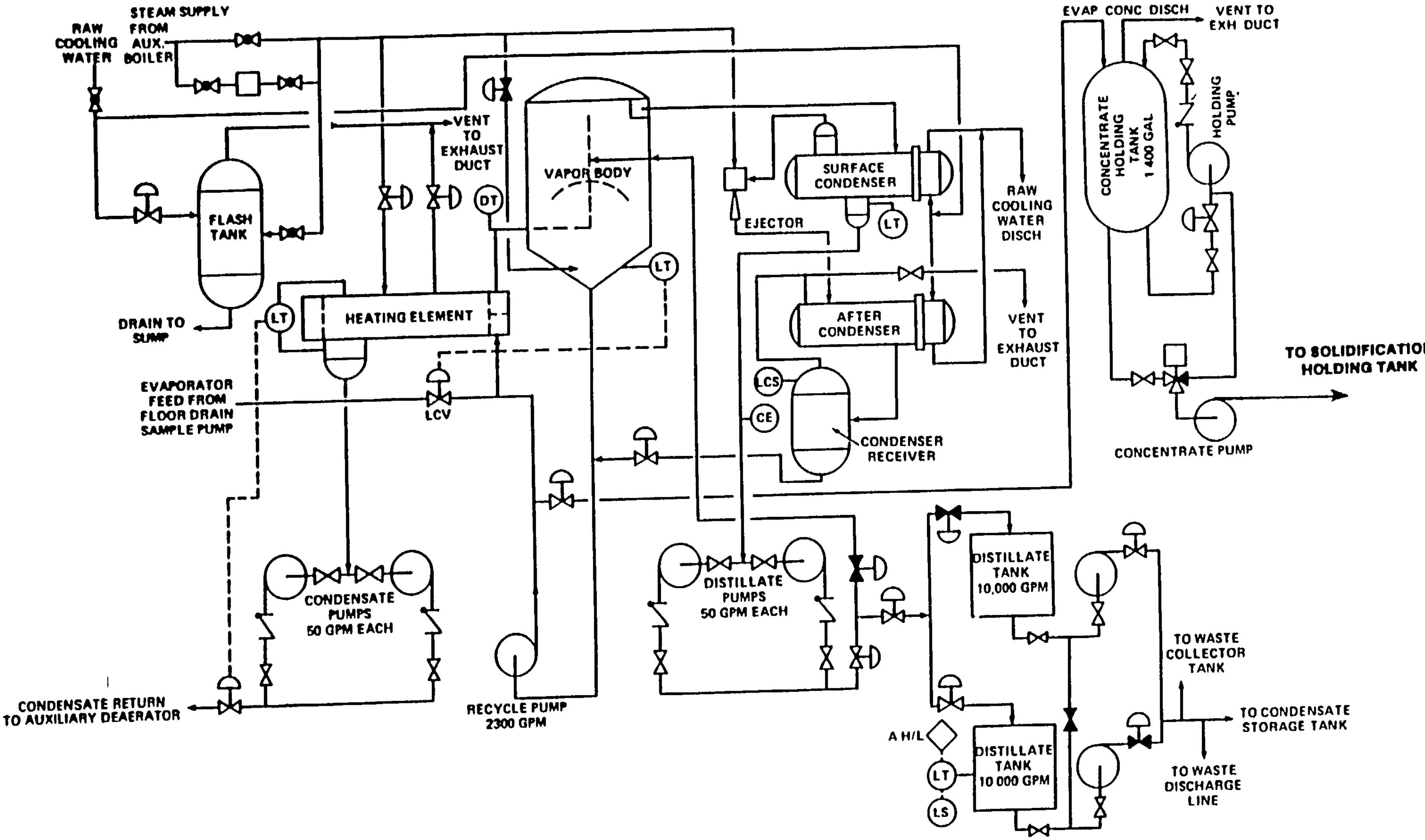

FIGURE 8.2–4 RADWASTE EVAPORATOR SYSTEM

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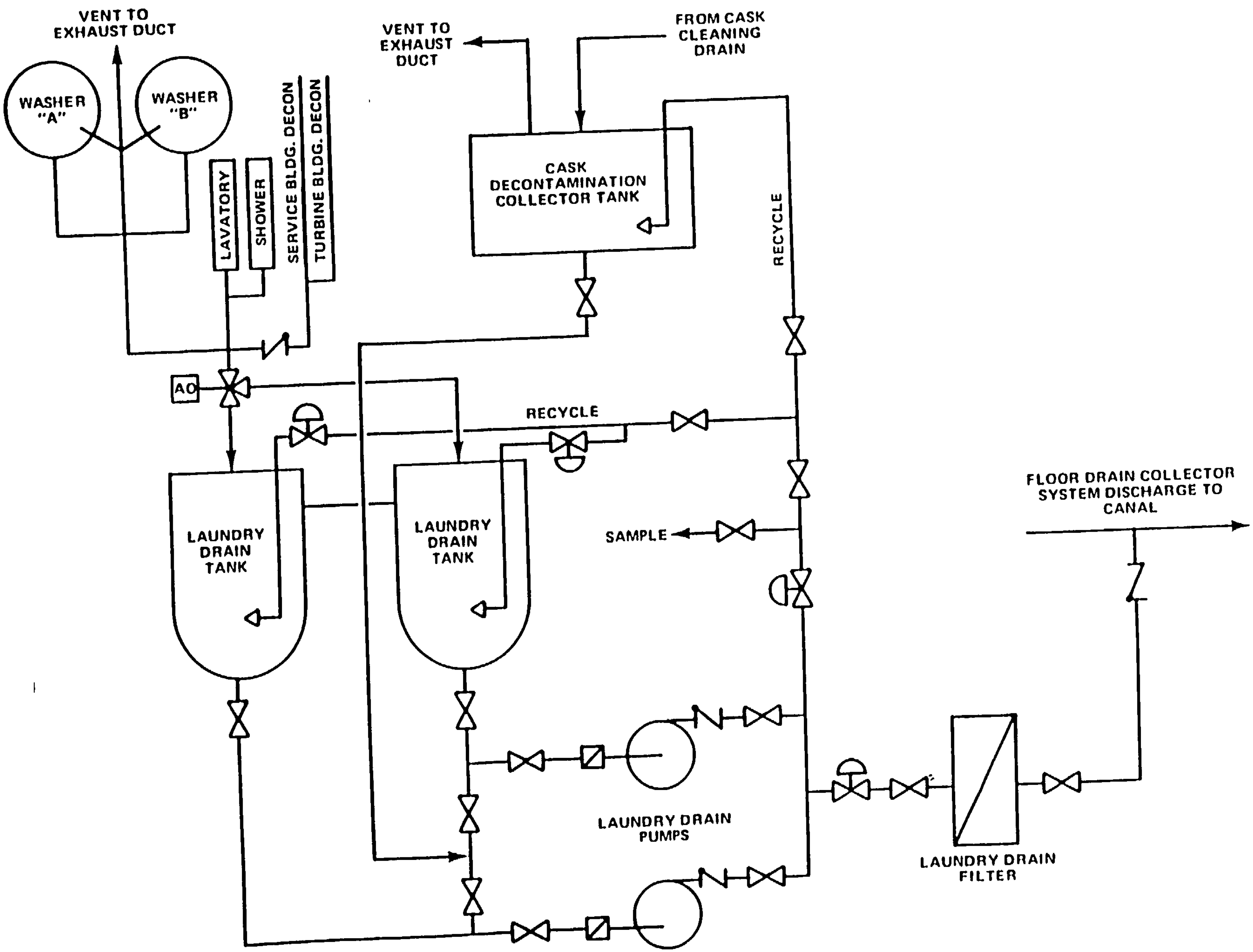

FIGURE 8.2 – 5 DETERGENT WASTE SYSTEM

Boiling Water Reactor
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Technology Manual

Chapter 8.3

Solid Radwaste System

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8.3 SOLID RADWASTE SYSTEM

Learning Objectives:

1. State the system's purposes.
2. List the three classifications of solid radwaste.
3. Place major system components in flow path order and explain the purpose of each for the Wet Solid Waste System.

8.3.1 Introduction

The purposes of the Solid Radwaste System are:

1. To collect, process, store, package, and prepare for shipment solid radwaste material produced through plant operations.

2. To comply with 10 CFR 71, 10 CFR 61, and U.S. Department of Transportation (DOT) regulations appropriate to the mode of transportation in 49 CFR 170 through 189.

The functional classification of the Solid radwaste System is that of a power generation system.

8.3.2 System Description

The Solid Radwaste System processes all solid radioactive waste products. The solid wastes are collected and processed according to the classifications of wet solid wastes, dry solid wastes, and irradiated reactor components.

Wet solid wastes consists of spent powdered ion exchange resins, filter media sludge, bead type ion exchange resins, and evaporator bottoms. These are stored, packaged, and prepared for shipment in the radwaste building.

Items of dry solid waste are colleoted in suitable containers located throughout the plant. The containers are lined with plastic bags, which are brought to the baler room in the radwaste building for temporary storage before baling.

Spent control rods and incore instrument stringers are stored in the spent fuel pool. They are loaded under water into shielded containers for shipment off site.

The Liquid Radwaste System provides many inputs into the Solid Radwaste System: spent powdered and bead resin, filter media, and evaporator bottoms.

Included in the Solid Radwaste System are the Phase Separator System, the Resin Dewatering Skid, and the Solidification Unit.

8.3.3 Phase Separator System Description

Spent powdered ion exchange resin and filter aid sludge are accumulated and stored in phase separator tanks. Batches of slurred materials are pumped into the tanks, where the solids settle out. The supernatant liquid is decanted off to make room for more slurry. Successive batches are accumulated until the desired settled slurry volume has been reached. After an appropriate decay period, the sludge is reslurried and pumped to the packaging area, where it is either dewatered in a high integrity container or solidified in concrete before transportation and subsequent burial.

High activity level sludge from the reactor water cleanup filter demineralizers is stored in three cleanup phase separator tanks. Normal operating requirements can be met with two tanks with a 60 day decay period. The third tank provides operating flexibility and additional decay time. Six condensate phase separator tanks are provided for storage of sludge from the condensate and also from the fuel pool filter demineralizers and the waste and floor drain filters. Sludge from the various sources may be mixed in the six tanks or segregated. Operating experience determines which is the better procedure.

The Phase Separator System is shown in Figure 8.3-1.

8.3.3.1 Component Description

The major components of the Phase Separator System are discussed in the paragraphs that follow.

Cleanup Backwash Receiving Tank

The cleanup backwash receiving tank is a stainless steel cylindrical vessel that has a conical bottom. It has a capacity of 3000 gallons and is equipped with a mixing air sparger, an overflow to the floor drain sump and a vent to the radwaste building exhaust duct. The Reactor Water Cleanup (RWCU) System filter/demineralizer is backwashed to this tank through a 4 inch diameter inlet line. The accumulation of filter/demineralizer backwash is then removed by the cleanup backwash transfer pump.

Cleanup Backwash Transfer Pump

The cleanup backwash transfer pump is a 50 gpm centrifugal unit. The pump takes a suction on the cleanup backwash receiving tank and discharges to the cleanup phase separator tank. The pump is equipped with a low backwash receiving tank level trip.

Cleanup Phase Separator Tank

The cleanup phase separators are closed top stainless steel cylinders with conical bottoms. The phase separator has a capacity of 5000 gallons which is sufficient to hold two back-washes. Decant outlets are located three levels above the maximum settled sludge level. A bottom outlet leads to the cleanup sludge pump.

Cleanup Decant Pump

The cleanup decant pump is a 56 gpm centrifugal unit drawing a suction from three different levels on the phase separator. After settling for at least 4 hours, the phase separator decant is pumped to the waste collector tank (Section 8.2) for further processing. Sludge batches ar accumulated in the phase separator for a period of several weeks or until a predetermined level is reached.

Cleanup Sludge Pumps

Each of the two centrifugal cleanup sludge pumps has an output of 200 gpm. The suctions are cross connected and draw from the bottom of the phase separator. The discharge of the pumps is directed to the solid waste packaging systems. This discharge is in the form of a concentrated slurry. To ensure a complete pumping, part of the sludge discharge flow is directed through a set of eductors located in the settling region of the phase separator. A flow through the eductors is maintained throughout the slurry transfer period.

Waste Backwash Receiving Tank

The waste backwash receiving tank is similar to the cleanup backwash receiving tank, it has a capacity of 7600 gallons. It receives filter and filter/demineralizer backwash from the waste collector filter, the floor drain collector filter, and the fuel pool cooling and cleanup filter /demineralizer.

Waste Backwash Transfer Pumps

The waste backwash transfer pumps are similar in design to the cleanup backwash transfer pump; they have an output of 450 gpm. The discharge of the two pumps is directed to the condensate and waste phase separators.

Condensate Backwash Receiving Tank

The condensate backwash receiving tank is similar to the cleanup backwash receiving tank, it has a larger capacity of 8500 gallons. It receives filter/demineralizer backwash from the condensate system filter/demineralizers.

Condensate Backwash Transfer Pump

The condensate backwash transfer pump is similar in design to the cleanup backwash transfer pump; it has an output of 450 gpm. The condensate backwash pump discharges to the condensate and waste phase separators.

Condensate and Waste Phase Separators

The design and construction of the condensate and waste phase separators is similar to the cleanup phase separators. The capacity has been increased to 12,500 gallons, and six phase separators are connected in parallel to accept the larger flow rates from both the waste backwash and condensate backwash receiving tanks.

Condensate and Waste Decant Pumps

Two condensate and waste decant pumps are connected to take a suction on any of the six condensate and waste phase separators. The pumps are 480 gpm centrifugal units discharging to the waste collector tank (Section 8.2). Suction points from three different levels are provided. Decant operation is similar to that described for the cleanup decant pump.

Condensate and Waste Sludge Pumps

The condensate and waste sludge pumps are 200 gpm centrifugal units. The pump suctions are cross connected to allow either pump to draw from any of the condensate and waste phase separators. The discharge is directed to the solid waste packaging system and is connected in a similar fashion to the cleanup sludge pumps.

8.3.4 Solidification Unit Description

To treat and solidify wet solid waste, the solidification unit uses Portland Cement and chemical additives such as spent powdered and bead resin, filter media, and evaporator bottoms. The solidification equipment consists of a control panel with indicators, a cement addition hopper, a cement fillhead, a pump skid, and a waste liner.

The waste is transferred to the waste liner by the condensate and waste sludge pumps and is then mixed in the liner with Portland Cement and chemical additives. The hydrolysis of the cement results in an exotherm, that raises the temperature of the waste liner. This increase in temperature facilitates curing of the cement. After a period of about 48 hours, the cemented waste liner can be safety transported to the burial site. If the Process Control Program (Waste Solidification Formula) is correctly followed, then the solidified waste should comply with the waste form criteria of 10 CFR 61.

8.3.4.1 Component Description

The major components of the solidification unit are discussed in the paragraphs that follow.

Cement Fill Head

The Cement Fill Head is a stainless steel cylinder containing connections for the waste line, chemical additives, and cement. In addition, it supports the hydraulically operated mixing blade, which mixes the solidification media, chemical additives, and the wet solid waste. A vent line is provided to the full heat to vent any offgas or dust that might be generated in the mixing process. A video camera mounted inside the fill head monitors the progress of the waste solidification.

Control Panel

The Control Panel contains the switches to control the hydraulic mixing blade, the alarm indication for overfill of the waste liner, the monitor for receiving the picture from the Fill Head video camera and a temperature recorder to monitor and record the exotherm from the cement cure.

Pump Skid

The Pump Skid contains the pump for chemical addition, and the hydraulic motor pump unit which provides motive force for the fill head mixing blade.

Waste Liner

The waste liner is a carbon steel liner with a volume of 155 cubic feet. Solidifications are performed with the liner inserted into a shipping cask if radiation level is high.

8.3.5 Resin Dewatering Skid Description

Dewatering is the process in which residual water is pumped out of a high integrity liner or regular liner containing spent resin. This process is required if solidification is not performed in such a manner that the waste media and container will comply with burial site criteria and 10 CFR 61. The dewatering process uses an air-driven, double-diaphragm, positive displacement pump. For precoat media, there is a 1-1/2 inch manifold with four 3/4 inch valved inlet connections and a 1-1/2 in. outlet connection. Dewatering occurs when the pump provides a continuous suction on a vessel.This suction removes pumpable liquid to a predetermined quantity or percentage of the waste form. The suction time will vary according to the resin or precoat and vessel used. The vessel contains a matrix of piping with small perforations to allow for pumping of residual water. The water removed from a vessel is returned to the plants liquid waste treatment system.

8.3.6 Baling and Drumming Facilities

Compressible wastes are packed into 55 gallon drums with the baling machine. Material is placed loosely in a drum, and a ram on the baling machine compresses it. The process is repeated until the drum is full. The baling machine is enclosed, and is fitted with an exhaust blower and high efficiency filter to minimize release of airborne radioactive particles. Small sized, noncompressible items are packed loosely into 55 gallon drums, or are mixed with compressible materials and put through the baling machine.

Spent filter elements from filter demineralizers and laundry drain filters are placed in plastic bags when they are removed from service. The bagged elements are placed in sealed drums, which are stored in restricted access storage areas. Areas to hold the sealed drums are located in the basement of the radwaste building.

Spent elements from air and gas filtration systems are placed in plastic bags upon removal from service. If the radiation level is low, the elements are placed in corrugated paper boxes which are sealed with tape. The elements are stored in restricted access areas. Spent elements from the offgas filters, which may have a high radiation level, are bagged, placed in a plywood box, and transferred to a nearby shielded storage area by remote handling methods. After a period of decay, the containers are removed from the storage and prepared for shipment. Shielded containers are provided for shipment of filter elements, if required.

Large sized contaminated items are encapsulated in steel containers or encased in concrete for shipment off site.

8.3.7 Treatment of Irradiated Reactor Components

Spent control rods, incore instrument strings, and other irradiated reactor components are stored in the spent fuel pool. For the most part, these large items must be cut into smaller pieces for packaging using an underwater hydraulic cutter. The pieces are then loaded underwater into shielded containers for off site shipment.

8.3.8 System Interfaces

A short discussion of interrelations between this system and other plant systems is given in the paragraphs that follow.

Liquid Radwaste System (Section 8.2)

The Liquid Radwaste System provides most inputs to the Solid Radwaste System in the form of sludge and resins.

Condensate Transfer and Storage System (Section 11.6)

The CTS System supplies water for slurry pumping and flushing.

Service and Instrument Air System (Section 11.8)

The SIA System supplies sparging air to receiving tanks and separators.

8.3.9 BWR Differences

The discussion in this section is appropriate for any BWR of product lines BWR/2 through BWR/6. However, major differences exist at facilities, even facilities of the same product line. The differences are, to a large degree, a function of the architect engineer chosen by the utility, or the contractor chosen for mobile radwaste solidification and dewatering.

8.3.10 Summary

Classification:
Power generation system

Purposes:

1. To collect, process, store, package, and prepare for shipment solid radwaste material produced through plant operations.

2. To comply with 10 CFR 71, 10 CFR 61, and U.S. Department of Transportation (DOT) regulations appropriate to the mode of transportation in 49 CFR 170 through 189.

Components:
Phase separator equipment, solidification unit, dewatered skid, baling and drumming facilities

System Interfaces:
Liquid Radwaste System

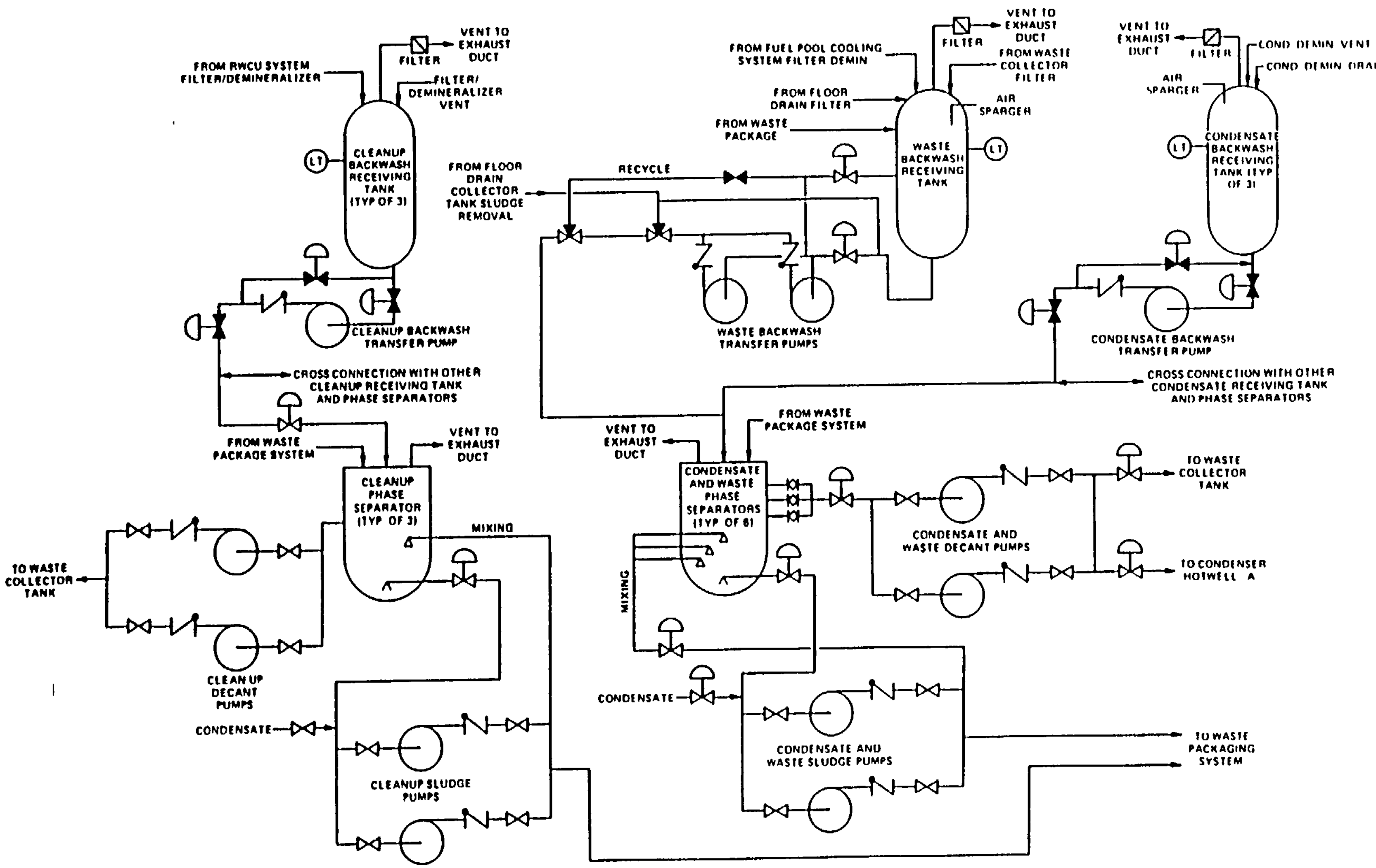

FIGURE 8.3 – 1 PHASE SEPARATORS

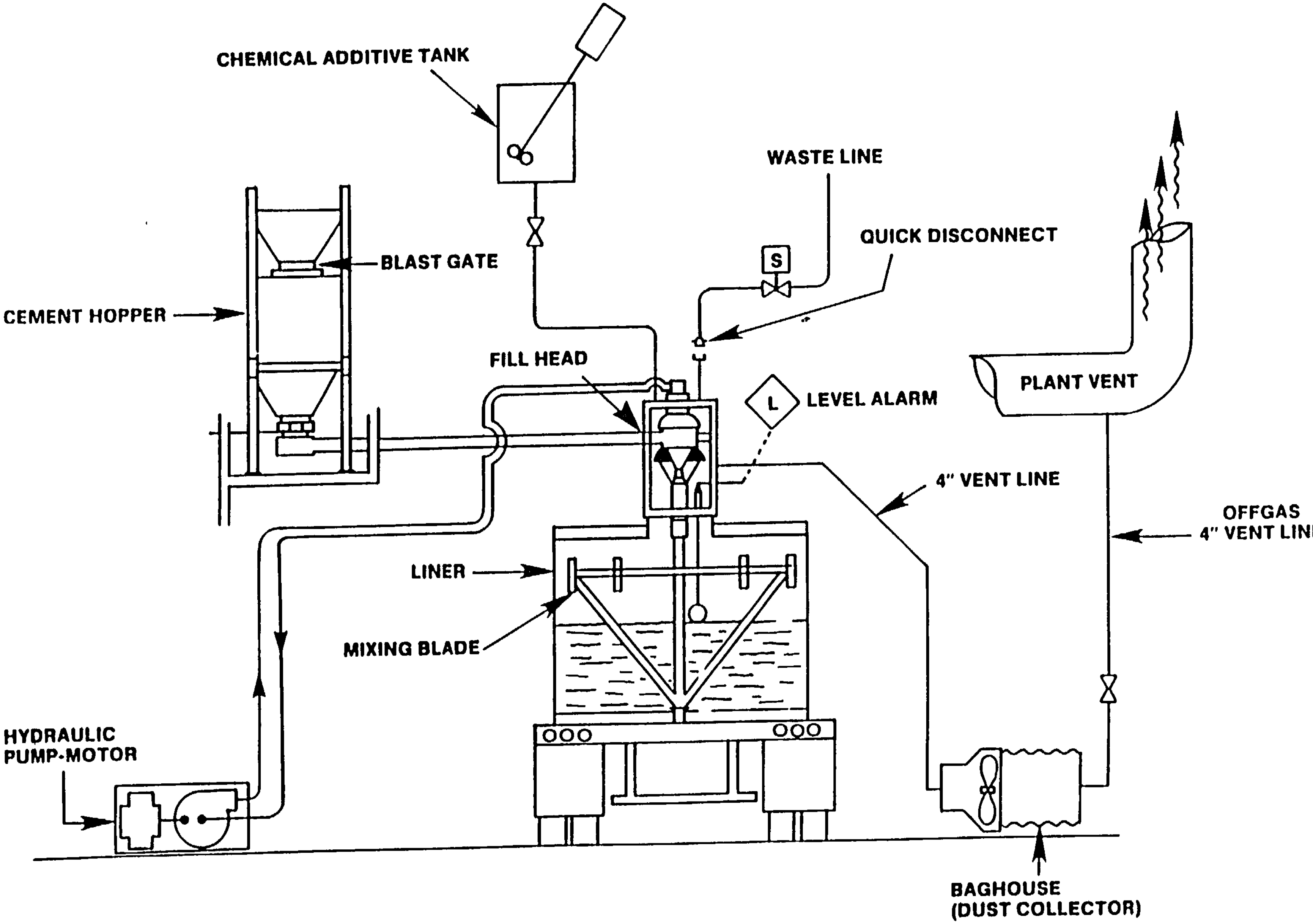

FIGURE 8.3 — 2 SOLIDIFICATION UNIT

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Chapter 9.0

Electrical Systems

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9.0 ELECTRICAL SYSTEMS

Learning Objectives:

1. Explain the purpose of the following major system components:
   a. Unit Generator
   b. Load Break Switches
   c. Main Transformer
   d. Reserve Station Service Transformer
   e. Normal Station Service Transformer
2. Explain the arrangement of electrical divisions.
3. List typical emergency core cooling system (ECCS) loads that are powered from the 4.16KV emergency buses.
4. List and explain the reasons for the diesel generator automatic start signals.
5. Explain the possible sources of power to the 4.16KV emergency buses.
6. Explain why load sequencing is necessary under accident conditions.
7. Explain the interfaces the Emergency AC Power (EP) system has with the following plant systems:
   a. Normal AC Power (NP) system
   b. DC Power System
   c. 120 AC Power System
8. Explain why failure of the DC power system is listed as a contributor to core damage frequency.

9.0.1 System Purposes:

9.0.1.1 Normal AC Power System

1. To provide adequate power to unit auxiliary loads needed for normal operation of the plant.
2. To deliver two physically independent offsite power supplies to the emergency buses, each capable of supplying the total station normal and emergency in-house loads. The two physically independent power supplies are the 138KV and the 69KV offsite transmission systems.

9.0.1.2 Emergency AC Power System

1. To provide a reliable source of AC power to all loads which are required for safe shutdown of the plant.

9.0.1.3 120 VAC Power Systems

1. To provide 120 VAC power to safety related loads and non safety related loads.
2. To provide uninterruptible 120 VAC power to systems that are not safety related.

9.0.1.4 DC Power Systems

1. To provide highly reliable 125 VDC and 24 VDC power to emergency buses and to equipment required for safe shutdown of the plant
2. To provide 125V DC power to balance of plant loads.

9.0.2 Design Criteria

The offsite power distribution network is the preferred source for station power to the normal and emergency buses. The offsite power distribution system includes two or more power sources capable of operating independently of the onsite or emergency power sources. It encompasses the grid, transmission lines, transmission line control systems, switchyard battery systems, and other distribution equipment. The general design criteria requires that electric power from the transmission network to the onsite electric distribution system be supplied from two physically independent circuits designed and located to minimize the likelihood of simultaneous failure under operating, postulated accident and environmental conditions.

The onsite site power distribution network distributes power to normal and emergency buses. The emergency buses, components and loads are required to be designed, built, and operated in accordance with IEEE class 1E standards. IEEE class 1E is the safety classification given to electrical equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment.

The emergency power system is designed to provide the functioning of structures, system, and components important to safety. The safety function for the emergency power system is to provide sufficient capacity and capability to assure that the specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operation occurrences and that the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.

9.0.3 Introduction

The plant electrical systems provide redundant, diverse, and dependable power sources for plant startup, operation, and shutdown. In the event of a total loss of offsite power (referred to as loss of preferred power), three diesel generators, a gas turbine and batteries are provided onsite to supply electric power to equipment necessary for the safe shutdown of the plant. The general format of this chapter is:

Normal AC Power (NP) System (Section 9.1)
Emergency AC Power (EP) System (Section 9.2)
120 VAC Power Systems (Section 9.3)
DC Power Systems (Section 9.4)

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Chapter 9.1

Normal AC Power System

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9.1 NORMAL AC POWER SYSTEM

9.1.1 System Introduction

The purpose of the Normal AC Power (NP) system is to provide adequate power to unit auxiliary loads needed for normal operation of the plant and to deliver two physically independent off site power supplies from the utility transmission network to safety related loads supplied from the emergency buses. The two physically independent power supplies are the 138KV and the 69KV AC offsite transmission systems (grid).

9.1.2 System Description

The NP AC system includes several transformers, a Normal Station Service Transformer (NSST), a Reserve Station Service transformer (RSST) and the Main Transformer (MT). Both of the station service transformers are stepdown transformers. The NSST steps 138KV AC down to 4160V AC and the RSST steps 69KV AC down to 4160V AC. Each of the stepdown transformers has two secondary windings. The NSST normally supplies NP buses 1A and 11 and the RSST normally supplies NP buses 1B and 12. Each of the transformers serves as a backup supply for the other. Loads associated with the four NP 4160V AC buses are listed in Table 9.1-1.

The Main Transformer (MT) is a step up (24KV to 138KV) transformer, which supplies the output of the Station Turbine Generator to the input of the NSST and the off site power distribution system grid.

Each of the NP 4160V buses supplies 4160V AC to 480V AC step down transformers.

9.1.3 Component Description

The major components of the NP System are shown in Figure 9.1-1 and are discussed in the paragraphs that follow.

9.1.3.1 Unit Generator

The rotating shaft of the main turbine is coupled to the unit generator rotor. The rotor supplies the rotating magnetic field necessary to produce electricity from the generator.

The unit generator design ratings are 820 MWe, 978MVA, 1800 rpm, 60 Hz and 24KV. The unit generator has some auxiliary support systems which are required for its operation.

The generator rotor windings and in some part the stator windings are cooled by the circulation of hydrogen gas within the generator. This gas is maintained at 60 psig and greater than 90% purity to supply adequate cooling and to prevent a hydrogen explosion within the turbine generator. The Hydrogen gas is pressurized to increase the heat removal capacity of the Hydrogen cooling system. A Hydrogen Seal Oil system is used to prevent the Hydrogen gas from escaping the generator and forming gas pockets in the turbine building. The seal oil is supplied by the Turbine Lubricating Oil system at a pressure of approximately 60 psig. Hydrogen is used for cooling because the thermal conductivity of hydrogen is seven times that of air and its density is 1/14 that of air. This means that heat can be removed by Hydrogen gas at approximately seven times the rate of air and less power is lost in circulating the cooling gas. The gas is cooled by two Hydrogen coolers. Loss of one of these coolers reduces the ability of the Hydrogen gas to cool the rotor and stator, and therefore reduces the generator load rating to 80%.

High purity, low conductivity water is used to cool the stator bars, high voltage bushings in the lower frame extension, and the exciter rectifiers. Water is used for this purpose because it has a high heat capacity and low viscosity. Less power is required to circulate water through small spaces in the center of the conductors, and more heat can be removed per unit volume of coolant flow than can be attained with other coolants. The electrical conductivity of water is kept to a minimum, less than 0.5 micromho/cm under normal conditions. The water is also continually filtered to reduce particles which could possibly cause electrical shorting in the stator bars. Loss of one of the stator coolers reduces the ability of the generator to produce electrical power without overheating, so the generator load rating is again reduced to 80%. If stator cooling is lost entirely, the main turbine trips after a 10 second time delay.

The main generator excitation system is a GE Alterrex system which uses an auxiliary AC generator (alternator-exciter) as a power source, since the excitation power requirements are relatively large (1860KW and 500V). The alternator-exciter is directly coupled to the main generator rotor and is driven by the main steam turbine. It is a three phase, 60 Hz, 4 pole, air cooled machine whose output is connected to a group of static rectifiers. The static rectifiers are divided into three units, each comprising a three phase solid state, silicon diode, rectifier. The DC output from these units is applied directly to the generator rotor field windings via the main collector slip rings and brush gear.

The output from generator is three phase AC. Each phase output is routed through a specially constructed conductor which is encased in a cooling duct. One duct encases only one phase and is cooled by forced air. The hardware is referred to as an isolated phase bus duct.

9.1.3.2 Generator Output Breakers - Load Break Switches

The main generator is supplied with two load break switches operated in parallel. A load break switch (LBS) consists of three (one per phase) generator output circuit breakers installed between the MT and the grid. Each load break switch is capable of transmitting 50% of the generator output. The load break switches are normally operated in a ganged mode. In the open position, the load break switch isolates the generator and allows off site power from the grid to be provided to the NP system via the NSST. In the closed position, the generator is connected to the generator transformer and provides power to the grid and NP system. The LBS also protects the generator transformer and main auxiliary transformers from faults within the unit generator windings. The LBS are high volume double throw, oil filled circuit breakers. The oil provides a high resistance medium between high voltage terminal points in the open position. The purpose of the LBS is to protect the turbine generator and main transformer from electrical faults. A list of the protective trips provided by the LBS is listed in Table 9.1-2.

The LBS are used to synchronize the generator to the 138KV AC offsite power system (grid). They are controlled from the generator section of the balance of plant main control board in the control room. Either LBS may be used to synchronize the generator to the grid. The breaker to be used must first be selected by a special keyed synchronizing selector switch. This switch connects the incoming and running voltages to a synchroscope and to two voltmeters. When the first LBS has been synchronized it is shut. The second breaker may be closed without selecting the synchroscope provided the first LBS is closed because the frequency and phase relationships between the main turbine generator and the grid were locked in when the first LBS was shut.

9.1.3.3 Main Transformers (MT)

There are two Main Transformers. Each consists of three single phase, forced oil and air cooled transformers. Leads from the isolated phase bus ducts of the unit generator are connected to the primary windings of the transformer while the high voltage leads are connected to the secondary windings. The Main Transformers serve as step up (24KV/138KV) transformers when the LBS is closed.

9.1.3.4 Normal Station Service Transformers (NSST)

The NSST is a stepdown (138KV/4160V) three winding transformer. The primary winding is supplied by a 138KV connection to the offsite power distribution network (grid). The NSST has two secondary windings. Two windings are used for voltage transient separation while starting Reactor Recirculation MG Set Drive Motors. The NSST is the normal preferred power source for two of the four 4160V AC NP buses. The NSST is also the normal preferred source of power for the 4160V AC EP buses. The NSST is a Nitrogen blanketed, oil/air cooled transformer. The NSST is supplied with redundant protection relaying schemes that are used to isolate the transformer from all electrical connections in the event of an electrical fault condition. The purposes of the NSST are:

1. to supply preferred power to nonsafety related 4160V AC NP system buses 1A and 11 during normal plant operations

2. to supply preferred power to 4160V AC EP system buses 101, 102, and 103 during normal plant operations

3. to act as a backup power supply to the 4160V AC NP system buses normally supplied by the RSST

9.1.3.5 Reserve Station Service Transformer (RSST)

The RSST is a stepdown (69KV/4160V) three winding transformer. The primary winding is supplied by a 69KV AC connection to the offsite power distribution network (grid). The RSST is normally energized and normally supplies 4160V AC NP system buses 1B and 12. The RSST is the backup supply for the 4160V AC NP system buses 1A, 11, and 4160V AC EP system buses 101, 102, and 103. If the supply breakers to the 4160 buses from the NSST trip an automatic transfer to the RSST will occur.

9.1.3.6 Station Gas Turbine

The gas turbine acts as a reserve power supply for the 69KV AC distribution network and can be aligned directly to the RSST. The gas turbine is not located on site, can be used as a peaking unit and is not designed to be switched onto or off of the 69KV AC distribution network in the loaded condition. The gas turbine is controlled by a grid load dispatcher and not controlled from the site.

The gas turbine was designed as a safeguard against a total loss of site power (station blackout). The impact of the addition of a third source of power to the NP AC system was the reduction in the likelihood of a station blackout to a very low probability.

9.1.3.7 4160V Normal Power AC Buses

There are four 4160V AC normal power system buses (1A, 1B, 11, 12). The normal power supply to NP buses 1A and 11 is the NSST. The NSST is directly connected, through the Main transformer, to the Station Turbine Generator, and through the normal transmission lines to the power distribution network. Buses 1A and 1B normally supply large motors only. Buses 11 and 12 normally supply smaller loads. Supply breakers to the Normal 4160V AC buses are 2000 amp fast acting breakers, which will automatically transfer to their backup supply when the normal supply is lost. Backup supply breakers have a 1200 amp capability and do not have the facility for fast transfer.

Typical loads supplied by the 4160V AC NP system buses are listed in Table 9.1-1.

9.1.3.8 Normal 480V Distribution

The 480V AC NP system consists of eight metal clad switchgear buses, combined through a bus tie breaker into four double ended buses. The 480V AC NP system buses are fed by 4160V AC NP system buses 11 and 12. Control power for the 480V AC switchgear is supplied by 125V DC. A one line drawing is presented in figure 9.1-2.

The 480V AC switchgears supply small motors (3/4 hp to 400 hp) and various step down transformers, for smaller loads such as lighting, power distribution panels, and motors of less than 3/4 hp.

The distribution of the NP 480V AC power to auxiliary loads is provided by secondary unit substations (SUS). A secondary unit substation consists of a primary section which provides for the connection of the incoming medium voltage 4.16KV AC circuit, a transformer section, and a secondary section which provides for the connection of feeders for motors, 480V AC power panels, and the motor control centers (MCC). The transformers have a primary winding voltage of 4.16KV AC and the secondary windings are at 480V AC. The transformers have automatically controlled forced oil and air cooling systems. The SUS circuit breakers are electrically opened and closed, but manual operation is possible; control switches are mounted on each SUS section. Each NP 480V AC normal bus and MCC can be energized from the adjacent 480V AC bus via the bus tie breaker if the normal power supply is not available due to transformer or feeder breaker maintenance. Before closing the bus tie breaker, the normal feeder breaker must be open.

The 480V AC motor control centers supply power to the small motors, motor operated valves, lighting distribution panels, and 120V AC power panels. Each MCC consists of various sized motor starters contained in cubicles on the motor control center. The starter contacts open and close electrically. Overload protection is provided with bimetallic electro mechanical relays included for each phase in a MCC cubicle. The MCC provides instantaneous protection for motors and time delay overcurrent protection for feeds to power panels.

The Normal 480V AC power system is designed for continued operation in the event of a loss of one of the 4160V AC NP system buses. The reason is no fast transfer capability with in the 480V AC NP system, but there are several electrical configurations available which increase the flexibility and availability of the system.

Components supplied by the 480V AC NP system include:

- 480V MCCs
- individual components
- stepdown transformers to 120V AC distribution panels
- battery chargers for the 125V DC batteries

9.1.3.9 Generator Bus Duct Cooling System

The generator bus duct cooling system consists of one fan with other supporting equipment. Air is discharged from the fan, passes through the generator bus ducts removing generated heat, passes through an air/water heat exchanger and is then returned to the fan. Cooling water is supplied by the turbine building closed loop cooling water system.

9.1.4 System Features and Interfaces

A short discussion of system operation and interfaces between this system and other plant systems is given in the paragraphs that follow.

9.1.4.1 Normal Operation

Under normal operating conditions, the NP system supplies AC power to part of the equipment required for normal plant operation. The turbine generator supplies power to the 138KV grid through a step up transformer referred to as the main transformer. The NSST receives power from the 138KV AC grid. The power then goes through the NSST which steps the voltage down from 138KV AC to the 4160V AC NP system buses. The RSST receives power from the 69KV grid and could receive power from an assigned gas turbine. The RSST and NSST step the voltage down to 4160V AC for use on the NP system and EP system 4160V AC buses. The voltage on the NP system and EP system 4160V AC buses is further stepped down by the 4160V AC switch gear to 480V AC for use on one of eight NP system 480V AC buses and one of three EP system 480V AC buses.

9.1.4.2 System Interfaces

The NP AC system interrelates with virtually every plant system. Table 9.1-1 gives a listing of the more important loads supplied by the system. Other important interrelations are discussed in the paragraphs that follow.

DC Power System (Section 9.4)

The DC Power System supplies control power to the NP AC system medium voltage switchgears and SUS circuit breakers.

Process Computer System (Section 6.1)

The Process Computer System collects data from the NP System and computes power system values. These calculated values are then used as inputs to other systems

Emergency AC Power System (Section 9.2)

The Emergency AC Power System is normally energized by the NP System.

9.1.5 BWR Differences

Major differences can exist in the electrical distribution systems from plant to plant. Some utilities use 6.9KV AC as the highest onsite voltage distribution. Other utilities use 13.8KV onsite voltage distributions. Most facilities have 4.16KV, 480V, and 120V AC distributions. Outgoing and incoming power to and from the transmission system (or grid) can be at several different voltages such as 500KV, 345KV, 161KV, or 138KV, depending on the specific utility. Most utilities do not have a gas turbine.

9.1.6 PRA Insights

In response to an initiating event this facility PRA identifies certain front line systems that are necessary to respond to the initiating event. Many of the front line systems need support systems in order to perform their function. Normal AC power, Emergency AC power and DC power are three of the support systems that were included in the analysis.

Loss of offsite power was one of the initiating events chosen for the PRA at this facility. The resulting core damage frequency from the loss of offsite power was very small because of the large number of ways that the facility has to power the 4160V AC emergency buses. The loss of DC power as a support function to other initiating events resulted in approximately 5% of the core damage frequency. The main source of the 5% contribution to the core damage frequency was the loss of DC control power to components that were important to the safe shutdown of the facility (example, DC control power to RCIC).

9.1.7 Summary

The Normal AC Power (NP) system provide power to unit auxiliary loads needed for normal operation of the plant and delivers two physically independent off site power supplies from the utility transmission network (grid) to safety related loads supplied from the emergency buses. The two physically independent power supplies are the 138KV and the 69KV AC offsite transmission systems (grid). The NP system has a quick transfer function which allows the transfer of loads from normal preferred power to backup preferred power if the backup preferred power is available. The NSST and RSST both serve normal and backup preferred power functions. The gas turbine provides an additional source of offsite power to the NP system.

Table 9.1-1
Normal 4160V AC Bus Loads

Bus 1A "A" Reactor Recirculation MG Set Drive Motor "A" Circulating Water Pump "A" Condensate Booster Pump 4160V AC Emergency Buses 101, 102, 103
Bus 11 "A" Turbine Building Service Water Pump "A" and "B" Screen Wash Pumps "A" Air Compressor "C" Circulating Water Pump 4160/480 Transformers
Bus 1B "B" Reactor Recirculation MG Set "B" Circulating Water Pump "B" Condensate Booster Pump
Bus 12 Fire Pump "B" Condensate Pump "B" and "C" Air Compressors "D" Circulating Water Pump 4160/480 Transformers

Table 9.1-2
Load Break Switch Trips

Exciter alternator field breaker open
Unit current differential high - This is a phase to phase current difference within the LBS
Main generator field ground fault
Selected 123KV grid breakers - This is designed to prevent the main turbine from supplying facility loads without being connected to the grid.
Voltage to frequency ratio high
Main generator stator water cooling loss
Main generator transformer sudden pressure increase
Main generator field overvoltage
Main generator anti-motoring - This is sometimes referred to as reverse power.
Main generator transformer differential current
Instantaneous high current
Turbine main stop and control valves shut
Turbine intermediate stop and intercept valves shut
Main generator transformer cooling units all off

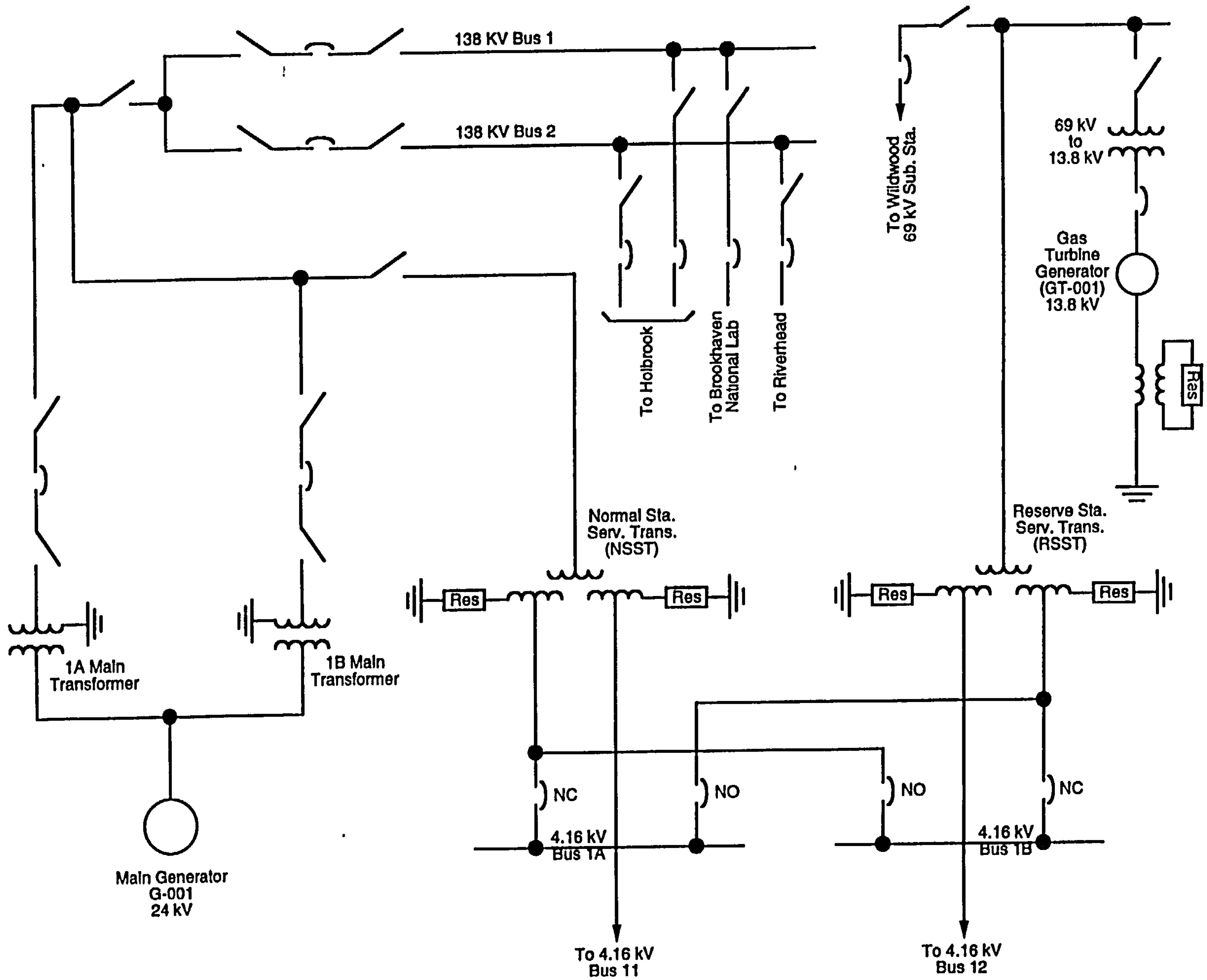

Figure 9.1-1 Main One Line Diagram–

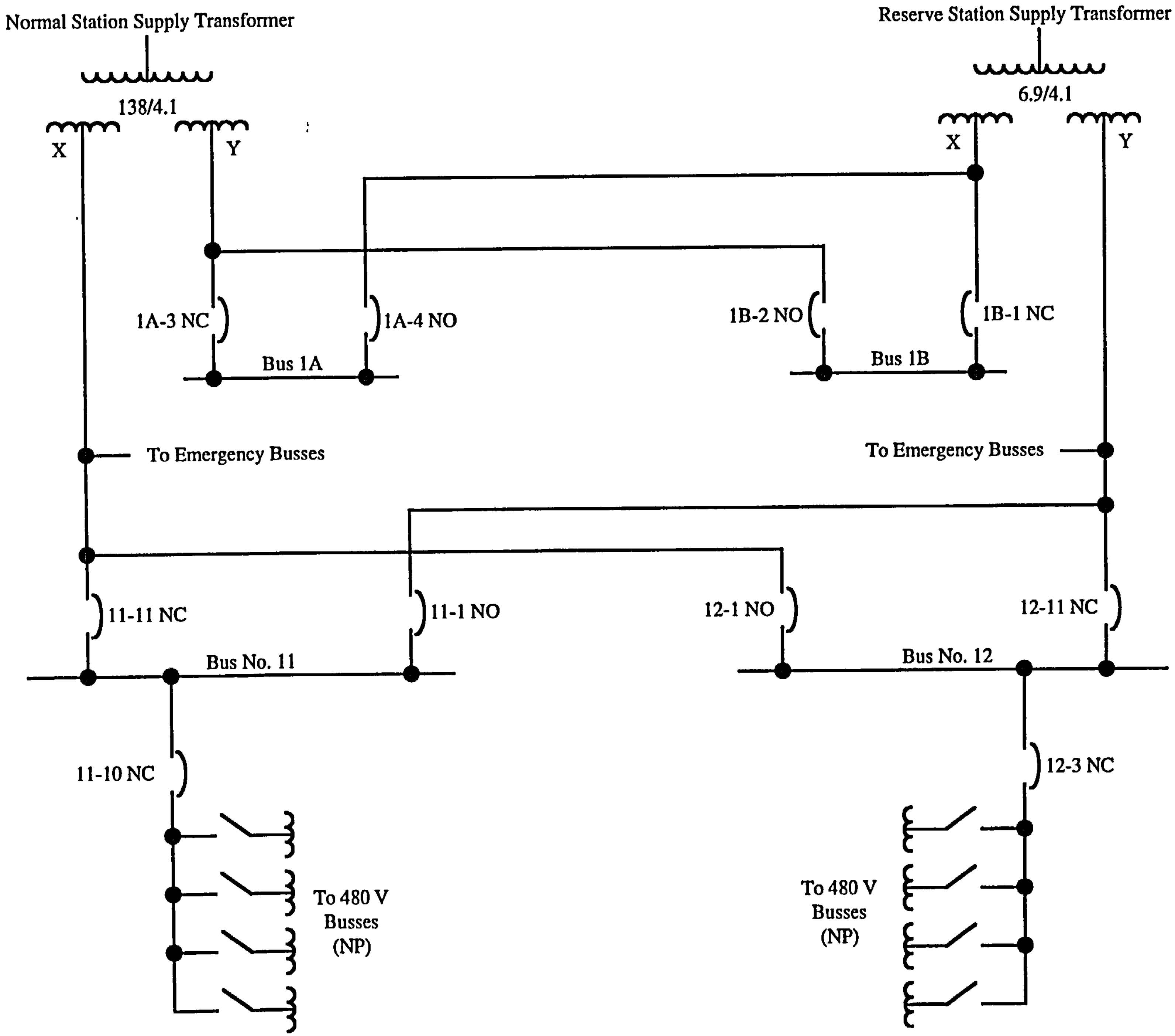

Figure 9.1-2 Normal Power Distribution

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Chapter 9.2

Emergency AC Power System

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9.2 EMERGENCY AC POWER SYSTEM

9.2.1 Introduction

The purpose of the Emergency AC Power (EP) system is to provide a reliable source of AC power to all loads which are required for safe shutdown of the plant. The preferred sources of power to the EP system are the normal (NSST) and backup (RSST) supplies from the NP system. Onsite diesel generators provide emergency power in the event that all offsite power has been lost (loss of preferred power). The EP system is one of the engineered safety features at the facility, and as such is safety related (IEEE class 1E). Engineer safety feature equipment is divided into three electrical busses (divisions), any two of which are capable of bringing the reactor to a safe, cold shutdown, condition in the event of a loss of coolant accident. A one line drawing of the EP system is presented in Figure 9.2-1.

9.2.2 System Description

The EP system consists of 4.16KV AC switchgears, 480V AC secondary unit substations (SUSs), motor control centers (MCC), power panels (PP), 4160V AC distribution lines, instrumentation and control equipment. The EP system also includes three diesel generators, and medium and low voltage distribution equipment. The EP system has several voltage levels. The primary distribution voltage level is 4.16KV AC; the secondary distribution voltage level is 480V; and lighting and other small voltage loads are at 120V AC. The primary distribution voltage is supplied to large pump motors, ESF 480V-SUS transformers, and 480V AC distribution centers. The 4.16KV AC EP system is stepped down to 480 V AC by transformers for distribution to 480V AC EP MCC and 480V AC EP distribution centers. Typical loads connected to the 4160V AC and 480V AC EP busses are listed in Table 9.2-1.

The EP system has three electrically and physically independent 4160V AC buses referred to as divisions (orange, red, and blue). Each division is provided with separate onsite emergency sources, electrical buses, distribution cables, controls, relays, and other electrical devices. The normal (preferred) power supply to each of the EP system 4160V AC divisions is the NSST. Each emergency power source (diesel generator) has sufficient capacity to provide power to its associated loads in the event of a Loss of Preferred Power (LOPP), to its associated EP system bus.

The redundant parts of the system are electrically and physically independent to the extent that no single failure, including an electrical failure, will cause a loss of power to redundant, safety related load groups. In the event of a LOPP, the EP switchgears are automatically connected to the diesel generators in sufficient time for safe reactor shutdown. In the event of a loss of coolant accident (LOCA) the diesel generators serve as a reserve power supply in case the preferred power supply is subsequently lost.

9.2.3 Component Description

The major components of the EP system are shown in Figure 9.2-1 and are discussed in the paragraphs that follow.

9.2.3.1 4.16KV AC EP System Switchgear

The EP system consists of three separate and independent 4.16KV AC buses (red - 101, blue-

102, and orange - 103). Each of these busses is connected to an associated diesel generator, and each has connections to two 4.16KV AC buses in the NP System. The three 4160V AC EP buses are the most reliable medium voltage AC buses in the plant. There are no bus ties between the three divisions at any voltage level within the EP System. They are physically and electrically independent from each other, so a failure of one bus has no effect on the operation of the remaining two buses.

Every EP system division can receive power from one of three power sources: the normal preferred source supplied through the NSST; the reserve preferred source supplied through the RSST; or the emergency source supplied from a diesel generator. Each of the three EP divisions has the capability to automatically switch from its normal preferred source of power to the reserve preferred source of power or to the emergency source of power. Every one of the three 4.16KV AC EP system switchgears has switching and interrupting devices, instruments, protective relays, a bus bar, main bus conductors, interconnecting wiring, accessories, supporting structures, and enclosures. The exterior of the switchgear has control switches and local indication equipment. All of the 4.16KV AC EP system switchgear buses are located in the auxiliary building. The interrupting functions of the switchgear include over current and bus ground fault functions.

9.2.3.2 Emergency Diesel Generators (EDG)

The emergency diesel generators supply emergency power to the 4160V AC EP system busses. The generator portion of the EDG is directly coupled to a large commercial diesel engine. Each diesel engine is a four stroke, eight cylinder, turbocharged, water cooled, fuel injected, Enterprise model R-48. Each engine is directly coupled to an air cooled, 4.16KV AC, 3 phase, 60 Hz, salient pole, synchronous generator. The continuous rating of each diesel generator is 3500 KW. The time required to achieve rated voltage and frequency is less than 10 seconds. All necessary auxiliaries directly associated with each diesel generator unit, such as cooling water, lubricating oil, circulating pumps, ventilating fans, and battery chargers are powered from their associated emergency bus.

See figures 9.2-2 through 9.2-5 for diagrams of these support systems. Each diesel generator unit is located, tested, maintained and operated independently of the other units.

Every diesel generator is provided with two independent full capacity air starting systems to furnish air for automatic and manual starting (Figure 9.2-2). The air starting systems include two air storage tanks, each capable of storing air for five normal starts of the engine. The air start systems also includes an air compressor, capable of recharging either tank. The starting air systems are fully redundant, and failure of one does not inhibit proper operation of the other.

Every EDG has a fuel oil system which includes components for the storage, transfer, and supply of fuel oil to the diesel (Figure 9.2-3). There is a fuel oil storage tank with sufficient capacity to operate the diesel generators for 7 days at maximum load demand.

Every diesel generator has its own independent cooling water system that dissipates heat generated by the diesel engine and lube oil cooler (Figure 9.2-4). Engine heat is absorbed by cooling water and transferred to the Standby Service Water System (SSWS) in the water cooler. The cooling system may be heated when the EDG is not in use. Heating this system maintains diesel engine cooling jackets at a minimum temperature, which minimizes the effects of cold starting the EDG.

A diesel generator lubrication system supplies lube oil to the diesel engine and generator bearing surfaces at controlled pressure, temperature, and cleanliness conditions (Figure 9.2-5). Each division diesel generator has its own independent lubrication system. The lubrication system is heated when the EDG is not in use. Heating the lubricating oil maintains diesel engine internals at a minimum temperature, which minimizes the effects of cold starting the EDG.

The diesel generators are protected against the following conditions during normal operations:

- generator reverse power
- loss of excitation
- overcurrent
- generator differential
- lube oil pressure low
- lube oil temperature high
- turbo oil pressure low
- jacket water temperature high
- crankcase pressure high
- overspeed

The diesel generators are protected against the following conditions during emergency operations:

- overcurrent
- generator differential
- overspeed

The difference between the protection afforded the diesel generator sets during normal and emergency operations is an attempt to optimize the availability of the components needed to support a safe shutdown of the reactor during accident conditions. The maximum EDG protection is provided during routine or surveillance performances of the diesel generator. During emergency operations it is desirable to minimize the number of protective trips to ensure that the diesel will continue to run for as long as possible, even though some less than desirable condition may exist. The diesel generator trips that are retained during emergency operation protect against major faults. Major faults are those that would cause immediate system disabling and major damage. Since, during accident conditions, the diesel generator is performing a safety related core cooling support function, the removed trip devices are not permitted to shut the generator down.

9.2.3.3 480V AC EP System Switchgear

The 4160/480 stepdown arrangement discussed previously in the NP system is nearly identical to the arrangement used in the EP system.

A secondary unit substation (SUS) consists of a 4.16KV AC to 480V AC three phase transformer supplying a 480V AC metal-enclosed switchgear, all on a common bus. The 480V SUS loads served consist of motor loads between 100 and 250 hp connected directly to the SUS switchgear, 480V AC motor control centers, and 480V AC distribution centers. The 480V SUS breakers function as both a protective device and a switching device for the 480V safety related loads. The protective functions supply ground fault and overcurrent protection to the 480V AC and 4160V AC systems.

The 480V AC EP system busses supply three battery chargers which in turn charge 125V DC battery busses A1, B1, and C1. Battery bus operation will be covered in section 9.4 of this chapter.

9.2.4 System Features and Interfaces

A short discussion of system features and interfaces between this system and other plant systems is given in the paragraphs that follow.

9.2.4.1 Normal Operation

During normal operation, the three 4.16KV AC EP system buses are fed from unit generator power or offsite sources through the NP System. The NSST transformer steps down the 138KV power supply to 4.16KV AC. Off site power is fed from the 138KV AC and 69KV AC substations through the NSST and RSST respectively, to the NP system. Power is delivered to the three 4160V AC EP system divisions from the 4160V AC NP system busses normally power by the NSST.

Power from the 4.16KV AC EP system busses is stepped down 480V AC. The 480V AC EP system busses are used to supply motor control centers, secondary unit substations, and battery chargers.

During normal plant operation the preferred source of power to the EP system is offsite power supplied through the NSST. Backup preferred power is supplied by the RSST. Each of the two transformers is capable of supplying the EP system by itself.

9.2.4.2 Loss of Preferred Power (LOPP)

Upon a loss of the normal source of power to the emergency busses, searching logic on the buses first checks the availability of the RSST source. If the RSST is available, a fast transfer to that source is made approximately 5 cycles after bus undervoltage is detected. The function is only available from the normal to the backup source of preferred power and not in reverse.
If any one of the 4160V AC EP system busses remains in an undervoltage condition for greater than 2 seconds, all of the diesel generators receive start signals. On occurrence of a LOPP, all the loads on the 4160V AC EP system busses (with one exception) and all the 480V AC EP system busses are shed. The exception to the load shed scheme is the control rod drive pumps which remain connected to the 4160V AC busses. All incoming source (NSST and RSST) supply breakers to the 4160V AC EP system buses are tripped. The diesel generator output breaker will only connect to the busses that are disconnected from the NSST and have an undervoltage condition. After the diesel is connected to its 4160V AC EP system bus then emergency loads are sequenced onto the 4160V AC EP system bus.

The diesel generator is connected to its bus only when all preferred sources are unavailable, all incoming source breakers have been tripped, and the diesel generator has reached rated speed and voltage. In the event an offsite power source becomes available, the operator can manually transfer the 4160V AC EP system busses back to the preferred offsite source.

The 4160V AC EP system busses must be manually realigned following automatic transfer to power sources. The transfer of power sources from an energized emergency bus is accomplished by manually paralleling the two power sources. When both power sources are synchronized, the breaker of the incoming power source is closed by the operator. This initiates an automatic trip of the running power source breaker after a 1 second time delay.

9.2.4.3 LOCA Without Loss of Preferred Power (LOPP)

On occurrence of a loss of coolant accident (LOCA) signal without a LOPP, all (except control rod drive pumps) the loads on the 4160V AC 480V AC loads are shed. The occurrence of a LOCA entails the same basic shedding and sequencing procedures as 4160V AC EP system bus undervoltage (LOPP). The loads required under LOCA conditions are different and in some cases larger than LOPP loads. The loads listed in Table 9.2-2, plus essential lighting and instrumentation, are automatically reconnected by a predetermined sequence to their respective buses. All three diesel generators start immediately after receiving the LOCA signal. The LOCA signal can result from either high drywell pressure of 1.69 psig or low reactor vessel level of -132.5 inches. The diesel generators will continue to run unloaded as long as the LOCA signal is present, even though preferred power is available to the 4160KV AC EP system buses. Loads that have not received a sequencing signal cannot be reconnected to the EP system buses until the LOCA signal has been cleared. The diesel generators can be manually shut down when the LOCA signal is cleared.

9.2.4.4 LOCA With LOPP

On occurrence of a LOCA with a LOPP, the EP system buses are shed of loads in the same manner describe above. All three diesel generators start immediately. The diesel generators are only connected to their respective emergency 4160V AC EP system buses if there is an undervoltage condition on that bus. To ensure fast starting and operation of large pump motors, emergency components automatically connected to the EP system buses by a predetermined sequence. The loading sequence that is selected by the EP system logic is dependent on which emergency signal (LOCA or LOPP) is first received. If the signals are received simultaneously as is postulated here, the LOCA sequence will dominate. The LOCA sequence is presented in Table 9.2-2. Any combination of two 4.16KV AC EP system buses is sufficient to bring the plant to, or maintain it in a safe shut down condition in the event of a LOCA and/or a LOPP. When the LOCA signal has been cleared, other loads can be manually reconnected to the EP system buses, and the diesel generators can be manually shut down if preferred power is available.

9.2.4.5 Testing

Periodic operability tests are performed on all three diesel generators. In order to test the capability of the EDG, one diesel generator can be paralleled with its preferred source of power, while the other diesel generators are maintained in standby readiness. One diesel generator is started, brought to rated speed and voltage, and then synchronized with a preferred source for test purposes. During testing, the diesel is not available to receive automatic start signals.

9.2.4.6 Diesel Generator Automatic Initiation Logic

The diesel generator automatic initiation logic actuates if undervoltage exists on any respective 4.16KV AC EP system bus; if reactor vessel water level is low, if drywell pressure is high, or if the division ECCS manual initiation is used. After reaching proper speed and voltage, the diesel generator is automatically connected to its 4.16KV AC EP system bus, if preferred power is not available to the bus. Once the diesel generator is automatically started, it continues to operate until the automatic start signal has been removed and it is manually shut down or one of the protective devices causes it to shut down.

9.2.4.7 System Interfaces

The emergency busses interface with many plant systems. Table 9.2-1 lists the more important loads supplied by the system.

Normal AC Power System (Section 9.1)

The NP system normally energizes the emergency busses and is the preferred source of power. Power is normally supplied through the NSST but can be supplied from the RSST.

120V AC Power System (Section 9.3)

The emergency power system provides emergency power to the 120V power system.

DC Power System (Section 9.4)

Control power for EP system circuit breakers and other components is provided by the DC Power system. The DC Power system is charged through battery chargers that are powered by the 480V AC EP system busses.

Process Computer System (Section 6.1)

The Process Computer System (PMS) collects data from the NP and computes system values.

Reactor Building Service Water System (Section 11.2)

The RBSWS supplies divisional cooling water to the diesel generators when they are operating.

9.2.5 BWR Differences

The discussion in this section is typical for a BWR/4. No standard design exists and each facility will vary. An example of how the designs vary from site to site is the addition of a gas turbine to this site. A proposed addition of three emergency diesel generators to this site is yet another difference. The proposal was not completed because the site was decommissioned.

9.2.6 PRA insights

In response to an initiating event this facility PRA identifies certain front line systems that are necessary to respond to the initiating event. Many of the front line systems need support systems in order to perform their function. Normal AC power, Emergency AC power and DC power are three of the support systems that were included in the analysis.

Loss of offsite power was one of the initiating events chosen for the PRA at this facility. The resulting core damage frequency from the loss of offsite power was very small because of the large number of ways that the facility has to power the 4160V AC EP system buses. The loss of DC power as a support function to other initiating events resulted in approximately 5% of the core damage frequency. The main source of the 5% contribution to the core damage frequency was the loss of DC control power to components that were important to the safe shutdown of the facility (example, DC control power to RCIC).

9.2.7 Summary

The Emergency AC Power (EP) system is to provides a reliable source of AC power to all loads which are required for safe shutdown of the plant. The preferred sources of power to the EP system are the normal (NSST) and backup (RSST) supplies from the NP system. Onsite diesel generators provide emergency power in the event of a LOPP. The EP system is one of the engineered safety features at the facility, and as such is safety related (IEEE class IE). EP system distribution equipment is divided into three electrical divisions, any two of which are capable of bringing the reactor to a safe, cold shutdown, condition in the event of a loss of coolant accident.

Table 9.2-1
4160V AC EP System Loads

Bus 101 - Red Division	
	RHR pump "A"
	Core spray pump "A"
	Service water pump "A"
	CRD water pump "A"
	480 SUS and loads
Bus 102 - Blue Division	
	RHR pump "B"
	Core spray pump "B"
	Service water pump "B"
	CRD water pump "B"
	480 SUS and loads
Bus 103 - Orange Division	
	RHR pumps "C" and "D"
	Service water pumps "C" and "D"
	480 SUS and loads

Table 9.2.2
LOCA Starting Sequence

Time following closure of EDG output breaker	
0 seconds	Control Rod Drive Pumps
2 seconds	RHR pumps (A, B, and C) start
7 seconds	Core spray pumps (A, and B) start and RHR pump D starts
12 seconds	Service Water pumps (A, B, and C or D) start
12 seconds	Reactor Building chillers (3A, 3B, 4A, and 4B) start
15 seconds	480V AC EP system buses

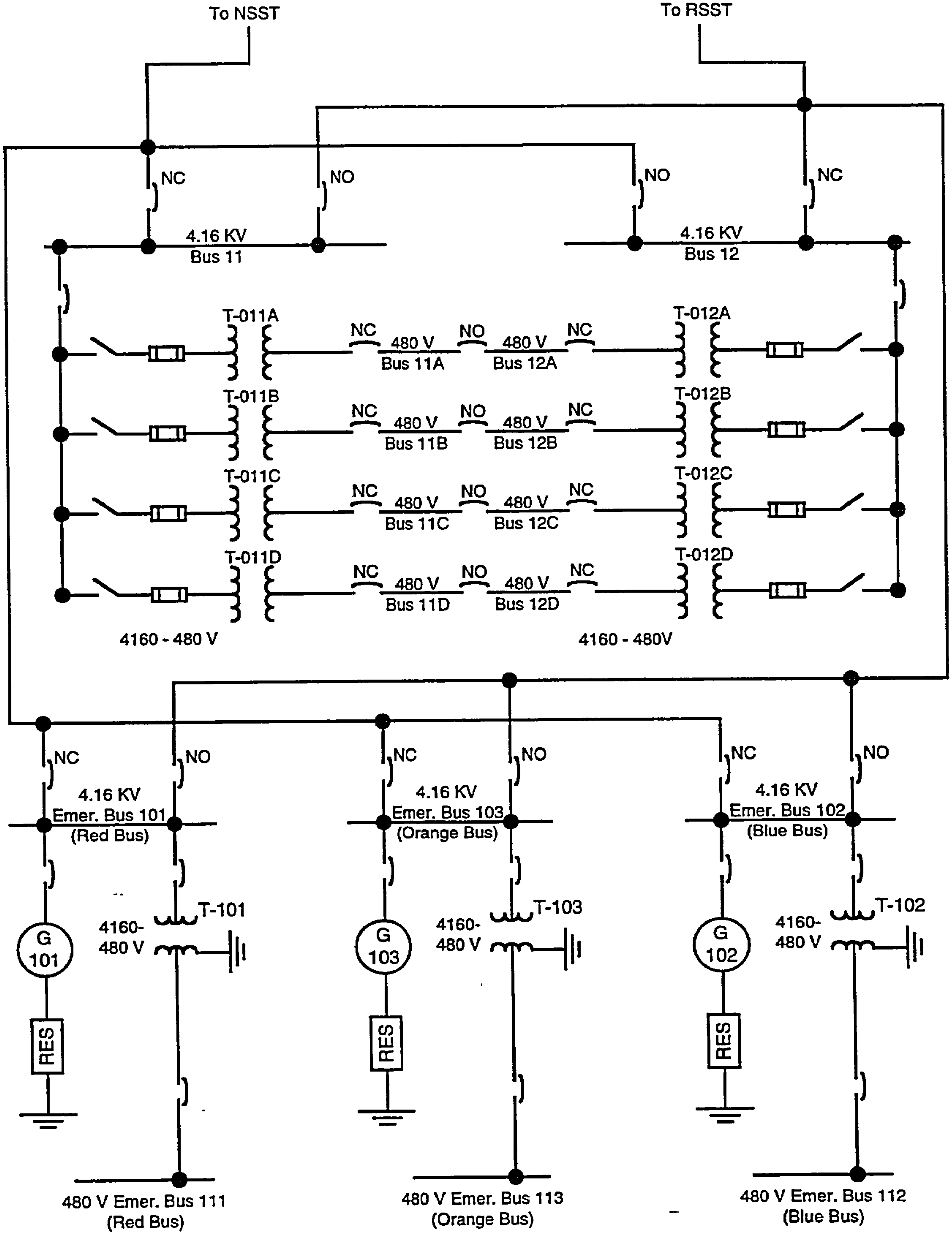

Figure 9.2-1 Emergency AC Power System

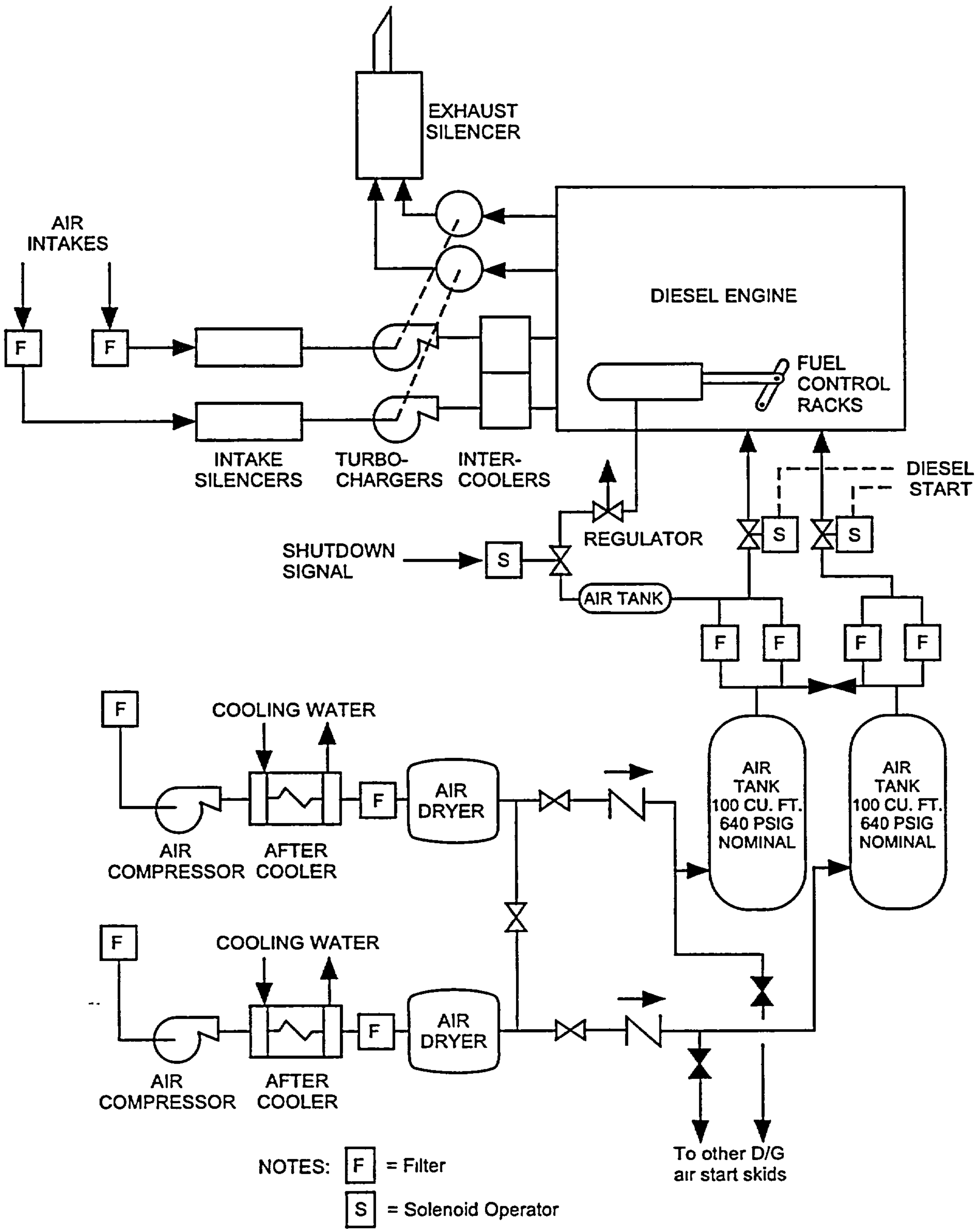

FIGURE 9.2-2 Diesel Starting Air

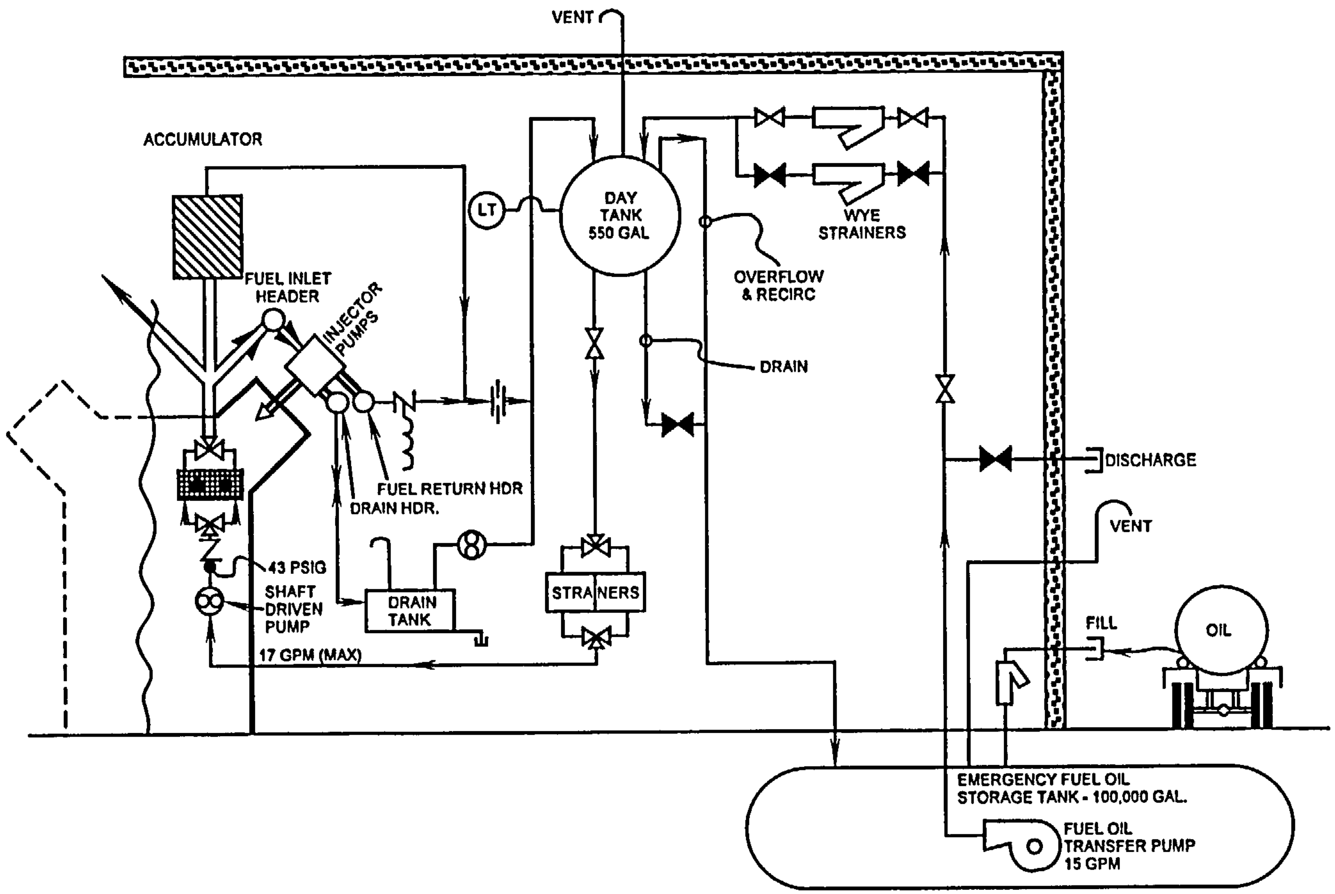

FIGURE 9.2-3 Diesel Fuel Oil System

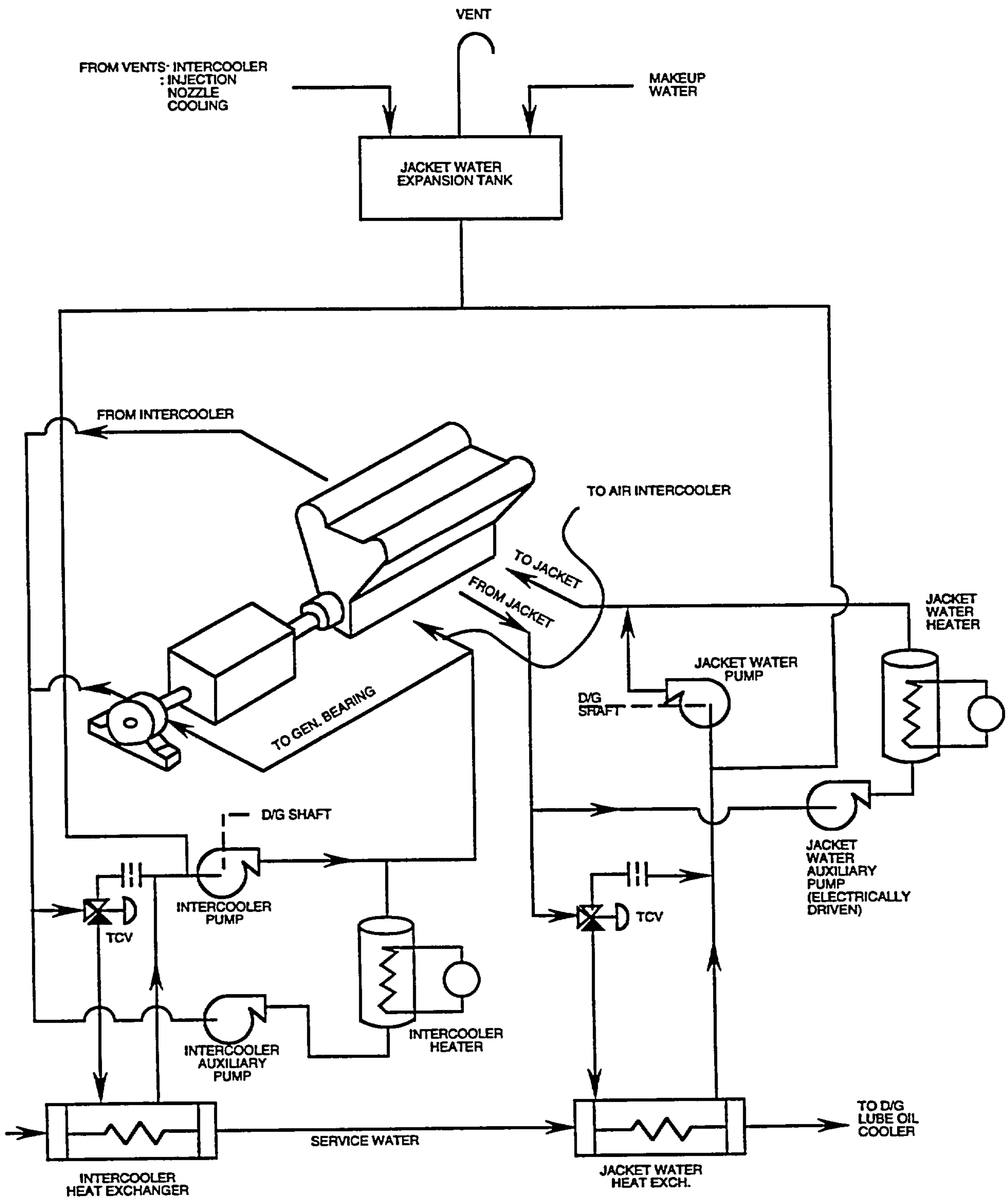

Figure 9.2-4 Generator Cooling Water

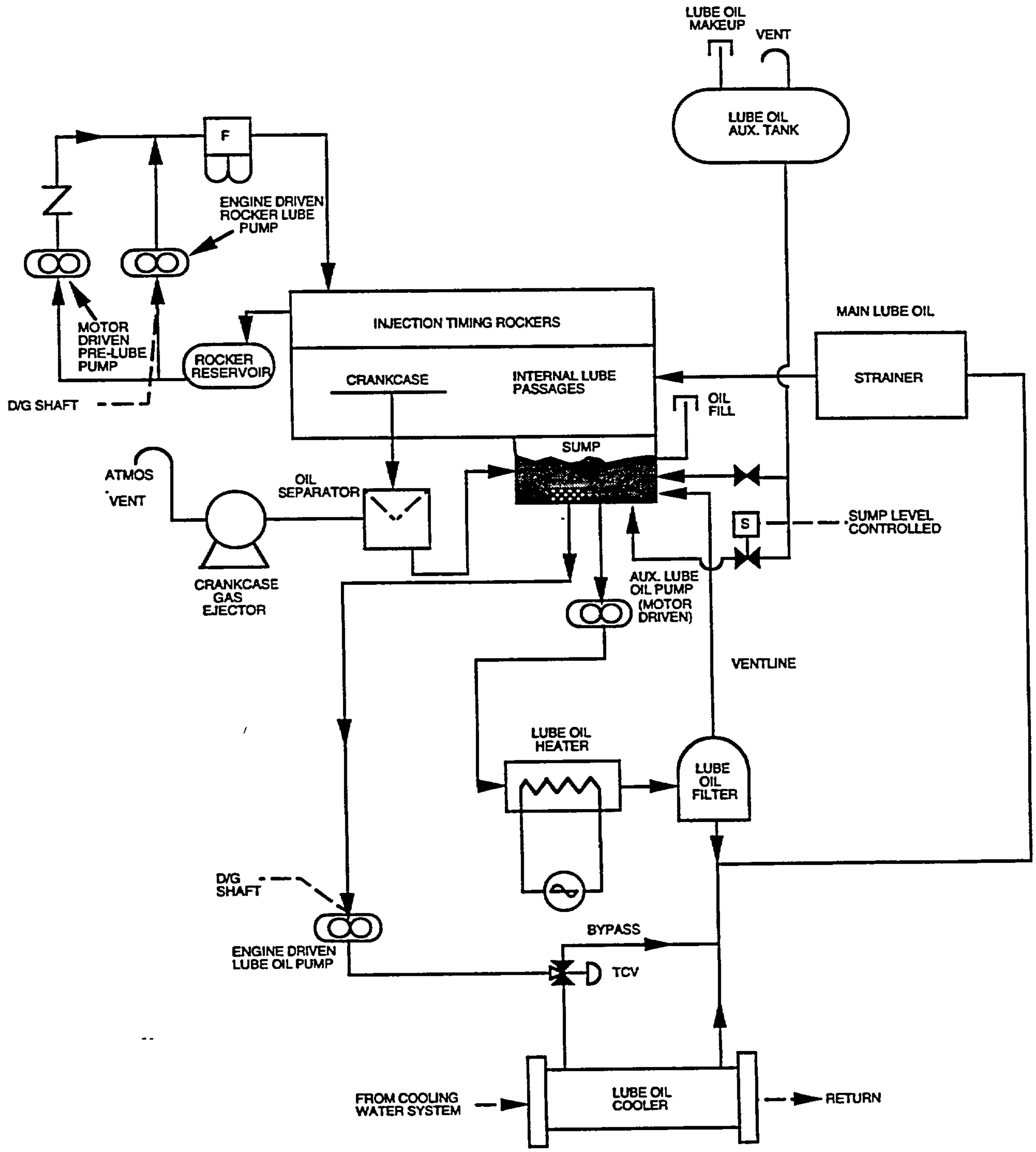

Figure 9.2-5 Diesel Generator Lube Oil System

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Chapter 9.3

120V AC Power System

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9.3 120 VAC POWER SYSTEMS

9.3.1 System Introductions

The 120 VAC Power Systems are divided into four systems; safety related control and instrument power system, normal control and instrument power system, reactor protection power system, and the uninterruptible power system.

9.3.1.1 Safety Related Control and Instrument Power System

The safety related control and instrumentation system consists of three independent subsystems. Each subsystem has a minimum of two power sources and associated distributed panels. Each power source is a single phase transformer with its primary connected to an emergency 480 VAC bus and its secondary connected to a distribution panel. The panels contain manually operated circuit breakers for protection of safety related circuits and devices.

9.3.1.2 Normal Control and Instrument Power System

The normal control and instrument power system consists of independent power sources and distribution panels to supply power to conventional instruments and noncritical monitors and controls. Each power source is a single phase transformer with its primary connected to a normal 480 VAC bus and its secondary connected to a distribution panel. The panels contain manually operated circuit breakers for protection of the circuits that supply instruments and monitors. Certain buses have automatic transfer from one power source to another where high reliability is desired during normal operations.

9.3.1.3 Reactor Protection System

The reactor protection power system consists of two independent and redundant power sources and an associated power supply panel. Each power source is a motor generator set with a high inertia flywheel that receives power from an emergency 480 VAC bus and delivers single phase 120 VAC to the distribution bus. There is an alternate source of power from a transformer with its primary connected to an emergency 480 VAC bus to allow for maintenance of a motor generator with no loss of reactor protection system function. For more information about the reactor protection system, see chapter 7.3.

9.3.1.4 Uninterruptible Power System

The purpose of the Uninterruptible Power Systems (UPS) is to supply 120 VAC power to non-safety related controls and instrumentation used for orderly operation of the plant. Since the UPS has the 125 VDC system (with batteries) as its alternate supply, its output should not be lost during the interval between a loss of offsite power and restoration of emergency AC by the diesel generators. The UPS output will continue for a minimum of two hours in the event of a total loss of AC power (blackout).

Each of the two systems consists of a rectifier, an inverter, static transfer switch, manual transfer switch, and a distribution panel (Figure 9.3-1). One system supplies power to the plant computer and the other supplies vital instruments and controls and part of the control room lighting. (There is a third unrelated system that supplies power to the station security system which will not be discussed).

Each inverter produces a 120 VAC output which is then supplied to a distribution panel.

The normal supply is an internal rectifier which receives power from an emergency 480 VAC bus. The backup supplies are from 125 VDC buses. An auctioneering circuit will allow the DC bus to supply the inverter without interruption if the AC source fails. A static transfer switch will allow the same 480 VAC bus to supply the 120 VAC distribution panel through a transformer in the event of an inverter failure. There is another 480 to 120 VAC path provided by the manual bypass switch for use during maintenance of either the inverter of the static transfer switch.

9.3.2 Component Descriptions

9.3.2.1 Internal Rectifier

The input of the internal rectifier is connected to the secondary of a step down transformer. Three phase AC is converted to DC by a full wave array that uses diodes and silicone controlled rectifiers (SCRs). The output voltage is maintained constant during varying input conditions by adjusting the amount of time in each half cycle that the SCRs conduct. This is called phase angle control. The output of the rectifier is connected to the inverter through a filter which is designed to reduce the ripple of the rectifier output.

9.3.2.2 Inverter

An inverter is a solid state device to transform DC power to AC power. The fundamental principle of operation of an inverter is the periodic switching of silicon control rectifiers to change the direction of current in a load. The frequency of the resultant wave is a function of the switching rate. The UPS synchronizes the frequency and phase of its output with the reference signal (the AC supply) as long as the frequency is within 1% of 60 Hz. The UPS will maintain its phase within 5 degrees of the reference signal during steady state conditions. This feature allows "make before break" load transfers. If the reference signal deviates from 60 Hz by more than 1%, the UPS will not follow, but will synchronize again when the reference returns to nominal. The UPS can supply 125% of full rated load for an unlimited time while maintaining output voltage within 10% of its nominal value.

9.3.2.3 Static Transfer Switch

The static transfer switch associated with the inverter makes transfers between the preferred source (inverter) to the alternate source (transformer) without interruption on a "make before break" basis, ensuring that there will be no transient or power interruption. The purpose of the transfer from the inverter to the alternate source is to continue to supply 120 VAC in the event of an inverter failure. This transfer is made automatically when inverter output drops below 106 volts. The transfer back to the inverter is by manual action only. The transfer from inverter to alternate supply can be accomplished manually as long as there is no more than a 5 degree phase difference between the two sources.

9.3.2.4 Manual Bypass Switch

The manual bypass switch allows for maintenance on the inverter or the static transfer switch by providing for "make before break" transfers between the inverter and the alternate source. The switch is interlocked with the static transfer switch so that a transfer can not occur unless the static switch is supplying power from the alternate source or the output voltage of the static switch is zero.

9.3.3 System Features and Interfaces

9.3.3.1 Normal Operation

Each UPS normally operates on power from an emergency 480 VAC bus. This 480 VAC power is stepped down in voltage, rectified, filtered, and sent to the input of an inverter. The inverter produces 120 VAC which is sent to a distribution bus. During this normal mode of operation, the 125 VDC power, which is used as a backup supply, is in standby. The static transfer switch and the manual bypass switch are both selected to the inverter output, so there is no input from the alternate AC supply.

9.3.3.2 Abnormal and Emergency Operation

The abnormal modes of operation for UPS occur when the 480 VAC is unable to supply power, or when either the inverter or the static transfer switch is unable to function properly. In the first case, a loss of 480 VAC, the 125 VDC input will supply the inverter with no interruption in output. In the case of malfunction or maintenance of the inverter, the static transfer switch automatically selects the alternate AC supply when the inverter output falls below 106 VAC. There is no interruption in power output because the static transfer switch does a "make before break" transfer. If the malfunction or maintenance includes the static transfer switch, it would be necessary to transfer to the alternate AC supply with the manual bypass switch. It is also a "make before break" transfer.

During emergency operations, the UPS should continue to supply 120 VAC to its loads as previously explained for normal and abnormal operations as long as either 480 VAC or 125 VDC is available. If offsite power is lost, UPS will use 125 VDC until the diesel generators supply the 480 VAC. For a sustained loss of all AC (blackout), the batteries will supply 125 VDC for at least two hours.

9.3.3.3 Interfaces

The 120 VAC power system interfaces with many plant systems. Loads include normal and emergency instrumentation and control systems and the plant computer. Other important interfaces are discussed in the paragraphs that follow.

Normal AC Power System (Section 9.1)

The normal AC power system supplies power to the normal control and instrument power system.

Emergency AC Power System (Section 9.2)

The emergency AC power system supplies power to the safety related control and instrument power system and the reactor protection system motor generator sets.

125 VDC Power System (Section 9.4)

The 125 VDC power system supplies backup power to the uninterruptible power system through inverters.

9.3.4 BWR Differences

The discussion in this section is typical for BWR/4 facilities. Specific buses and loads will vary from plant to plant. All BWR facilities have a 120 VAC power system by one name or another, but those of other BWR plants are somewhat different from the one in this discussion.

9.3.5 Summary

The purpose of the 120 VAC power system is to provide 120 VAC to safety and non safety related control and instrument buses, the plant computer, and to the reactor protection system. 120 VAC buses are supplied by 480 VAC buses through transformers, motor generator sets, or uninterruptible power supplies.

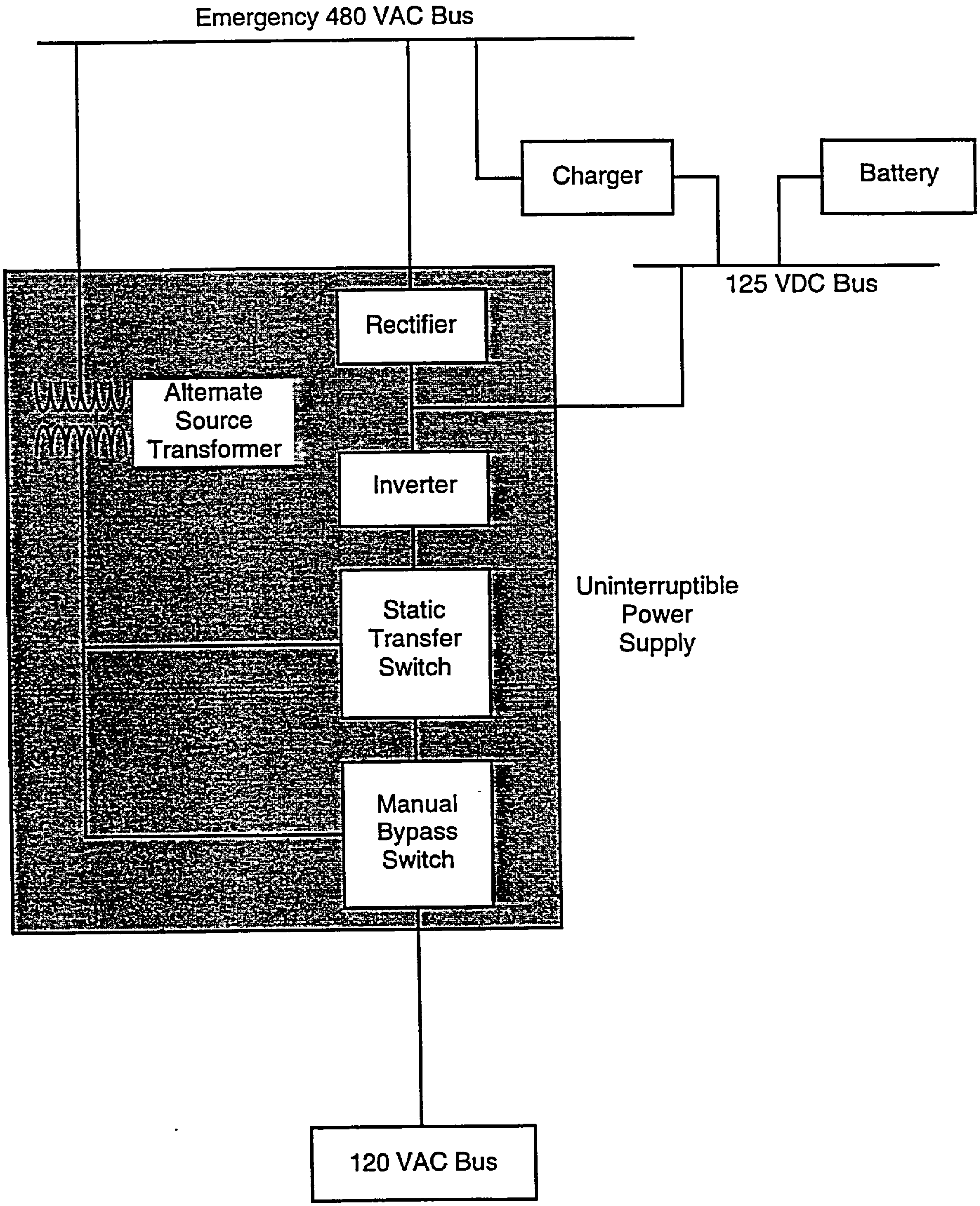

Figure 9.3-1 Uninterruptible Power Supply

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Chapter 9.4

DC Power System

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9.4 DC POWER SYSTEM

9.4.1 System Introduction

The purpose of the DC Power System is to provide highly reliable 125 VDC and 24 VDC to selected equipment required for safe shutdown of the plant and to loads that are essential for normal plant operation.

The 125 VDC system is divided into four separate divisions. Three divisions are for engineered safety features (ESF) equipment. This equipment includes ESF control systems (to prevent spurious operation on loss of AC power), equipment required to restore emergency AC supplies, and equipment that must operate at all times (including the interval between loss of offsite power and restoration of emergency AC power by diesel generators). The fourth division consists of four independent systems to provide power for non safety related systems. Two of the systems supply control and protective equipment, and auxiliaries required to achieve safe shutdown when offsite power is lost. The third system provides power for the emergency response facility, and the fourth for the security systems.

Each distribution bus has two sources as shown in Figure 9.4-1. One is a solid state battery charger that receives power from a 480 VAC bus, and the other is a 125 VDC battery.

The 24 VDC power system provides electrical power to the neutron monitoring system (source and intermediate ranges). This system is not safety related since the instruments supplied by the system do not trip the reactor or place the plant in a safe shutdown condition. There is a separate, unrelated 24 VDC system that supplies radwaste and process radiation monitoring systems that will not be discussed in this section. There are two separate 24 VDC distribution buses. Each bus consists of three wires (positive,negative, and ground) which are supplied by two batteries and two battery chargers. Both battery chargers associated with a distribution bus are supplied by an emergency 480 VAC bus through a step down transformer. Figure 9.4-2 shows a 24 VDC distribution bus.

9.4.2 Component Descriptions

9.4.2.1 Batteries

The 125 VDC batteries are pasted-plate lead acid type, made up of 60 cells, and sealed in clear plastic containers. Each cell has high and low electrolyte level marks, a built-in hydrometer reading tube, a vent hole thermometer, and a specific gravity correction scale on the pilot cell of each battery. The float voltage of each cell is 2.17V to 2.25V. The recommended equalizing and charging voltage is 2.33 volts per cell. There are ground alarm relays provided for each safety related bus.

The 24 VDC batteries are pasted-plate lead acid type that are made up of 12 cells in clear plastic containers. Each cell has electrolyte level marks and specific gravity and temperature monitoring.

9.4.2.2 Battery Chargers

The 125 VDC battery chargers are the normal source of power to the 125 VDC buses. The chargers are transformer rectifier units cooled by natural convection. They are rated at 300 amp continuous output. The rectifiers are silicon diodes and silicon controlled rectifiers (SCRs). The output is controlled by varying the phase angle of the SCRs. The output of the rectifier is smoothed by a smoothing circuit to reduce AC ripple. A current limiter will bias the output voltage if the current exceeds 360 amps. Alarms are provided for voltage greater than 145 and less than 105.

The 24 VDC battery chargers are convection cooled, single phase, rectifier units. The rectifiers use SCRs connected in a full wave bridge configuration. The output voltage is controlled by adjusting the firing angle of the SCRs. The output "float" voltage is set for 26 to 27, and the equalizing setpoint is 28 to 29 volts. A current limiter circuit will limit the output to 30 amps. The rectifier output is filtered by a choke circuit to reduce AC ripple. There are alarms for low voltage, low current, and loss of AC power input.

9.4.3 System Features and Interfaces

9.4.3.1 Normal Operation

During normal operations, the battery chargers will supply the normal steady state DC loads, and also "float" charge the batteries. The chargers have enough capacity to carry the steady state loads while recharging the batteries from minimum voltage to charged state within 24 hours. While the batteries are "floating", they are acting as filters against voltage transients.

9.4.3.2 Infrequent Operation

At specific time intervals as specified by the battery manufacturer, an equalizing charge is placed on the battery banks to bring weak cells back to within specific cell voltage limits and to extend battery life.

9.4.3.3 Abnormal and Emergency Operation

Loss of a battery charger causes annunciation of the appropriate alarms locally and in the control room. The associated battery will carry the loads of that bus until the battery charger is again available. If there is a loss of 480 VAC supply, the batteries will carry the loads until AC power is restored. A loss of offsite power will cause a loss of AC until the diesel generators restore emergency AC power in 10-12 seconds.
The worst case scenario for DC power systems occurs when there is a loss of coolant accident (LOCA) coincident with a loss of offsite power. If the diesel generators do not restore emergency AC power (blackout), the batteries will carry the load until emergency AC is restored. The 125 VDC batteries will be loaded heavily during the first minute due to initiation of engineered safeguard equipment. After this initial period, loads will be reduced to steady state conditions. The 125 VDC batteries can meet worst case loads for two hours in the event of a blackout. The 24 VDC batteries can supply its loads for four hours with no output from the battery chargers.

9.4.3.4 Interfaces

The DC power system interfaces with many plant systems. Table 9.4-1 lists the loads supplied by the safety related buses A1, B1, and C1. Other important interfaces are discussed in the paragraphs that follow.

Normal AC Power System (Section 9.1)

The normal AC power system supplies power to the non safety related battery chargers.

Emergency AC Power System (Section 9.2)

The emergency AC power system supplies power to the safety related battery chargers.

120 VAC Power System (Section 9.3)

The 125 VDC power system supplies backup power to the uninterruptible power system through inverters.

9.4.4 BWR Differences

The discussion in this section is typical for BWR/4 facilities. Specific buses and loads will vary from plant to plant. All BWR facilities have a DC power system by one name or another, but those of other BWR plants are somewhat different from the one in this discussion.

9.4.5 Summary

The purpose of the DC power system is to provide highly reliable 125 VDC to safety and non safety related loads and 24 VDC power to the neutron monitoring system. All DC buses are supplied by a battery charger that will carry the normal loads and maintain a charge on the battery. Each bus has a battery that will supply the bus in the event of a loss of power to the charger or a failure of the charger.

Table 9.4-1 Safety Related 125 VDC Loads

Bus A1

Safety related loads (division I):

Motor operated valves for:
- Reactor core isolation cooling (RCIC)

Pump motors for:
- RCIC condenser vacuum pump
- RCIC condenser condensate pump
- Diesel generator 101 fuel oil pump

Control power for:
- Backup scram trip system A
- Reactor high level trip system C
- High pressure coolant injection (HPCI) system (backup isolation controls)
- RCIC system
- Nuclear steam supply shutoff system (NSSSS), division I
- Automatic depressurization system (ADS), division I
- Residual heat removal (RHR) system
- Core spray (CS) system, division I
- Steam leak detection system, division I
- Recirculation pump trip system, division I
- 4160V and 480V emergency switchgear, division I
- Diesel generator 101
- Safety related ventilation systems, division I
- Auxiliary relay panel, division I
- CO_2 detection panel, relay room, division I

Field flashing for diesel generator 101

Non-safety related loads:

Plant process computer (via uninterruptible power supply)

Table 9.4-1(continued) Safety Related 125 VDC Loads

Bus B1
Safety related loads (division II): Motor operated valves for: HPCI system Main steam line drain system RHR system Reactor water cleanup system (RWCU) Pump motors for: HPCI turbine bearing oil pump HPCI condenser vacuum pump HPCI condenser condensate pump Diesel generator 102 fuel oil pump Control power for: Backup scram trip system B Reactor high level trip system B HPCI system RCIC system (backup isolation controls) NSSSS, division II ADS, division II RHR system, division II CS system, division II Steam leak detection system, division II Recirculation pump trip system, division II 4160V and 480V emergency switchgear, division II Diesel generator 102 Safety related ventilation systems, division II CO_2 detection panel, relay room, division II Field flashing for diesel generator 102
Non-safety related loads: None

Table 9.4-1(continued) Safety Related 125 VDC Loads

Bus C1
Safety related loads (division III): Pump motor for: Diesel generator 103 fuel oil pump Control power for: Diesel generator 103 4160V and 480V emergency switchgear, division III Safety related ventilation systems, division III CO_2 detection panel, relay room, division III Field flashing for diesel generator 103
Non-safety related loads: Uninterruptible power supply

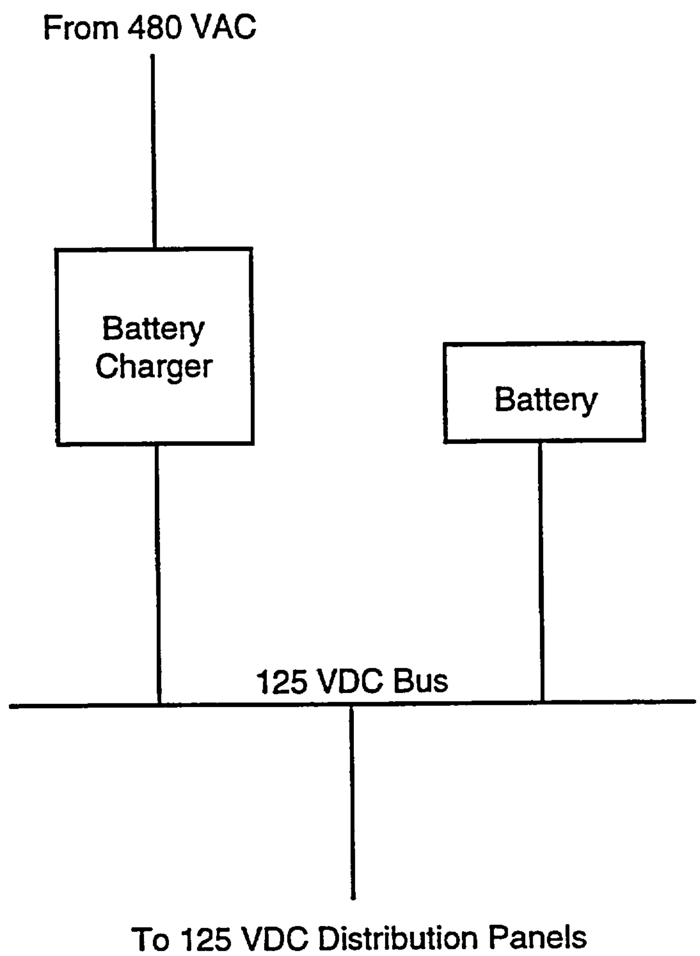

Figure 9.4-1 Typical 125 VDC Distribution

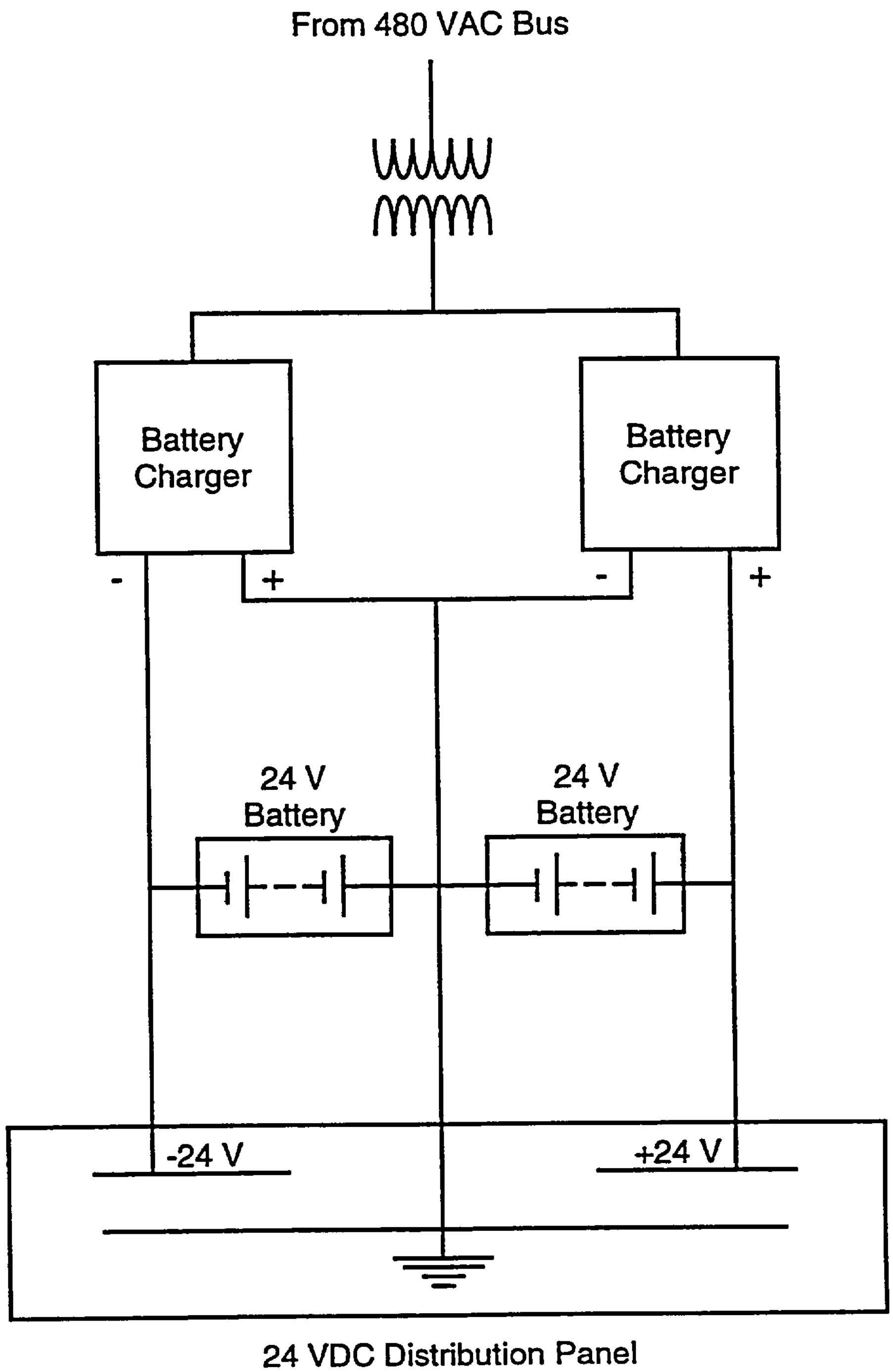

Figure 9.4-2 Typical 24 VDC Distribution